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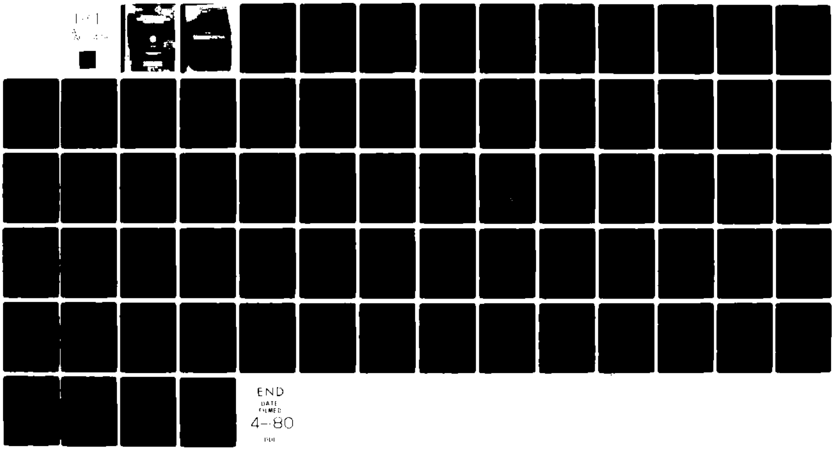

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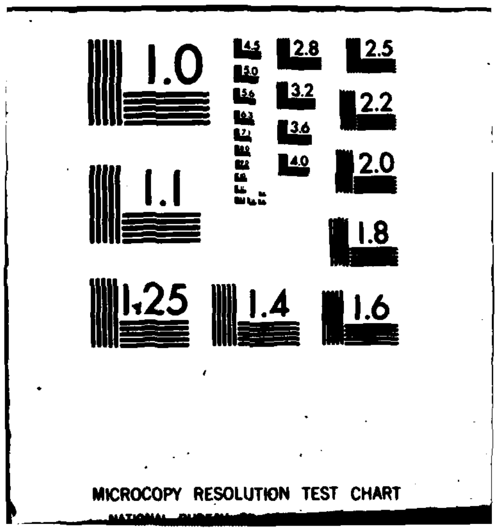
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16. Abstract

The purpose of this study is to provide first order estimates of the benefits of reduced separation standards under Advanced Vortex System (AVS) operations.

Benefits associated with conceptual Advanced Vortex Systems (AVS) are quantified from a delay reduction viewpoint. The study is equally applicable to airborne vortex alleviation technology or to ground or air-based vortex avoidance systems. Conducted as a first cut, exploratory analysis, the research compares the delay consequences of three sets of successively closer interarrival standards against the option of maintaining today's rules or a combination of today's and 3 nmi separations. The analysis was performed for only IFR weather conditions, since minimum required separation standards are not defined for VFR conditions. Three sets of standards were selected as representative of possible AVS capabilities. Substantial delay savings are shown to be possible even with demand growth below that projected to occur across the 1985 through 1995 analysis time period. The benefits are sufficiently large as to warrant a substantial research and development investment into an AVS program.

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CONCLUSIONS AND RECOMMENDATIONS

Significant runway-related delay savings appear to be available from reduced arrival and departure separations. Development of AVS capability is the key element for the achievement of inter-arrival standards in the vicinity of 2.0 to 2.5 nmi. Based upon the magnitude of the operating savings reduced separations appear to offer, it is recommended that the development of AVS be pursued as a priority research and development item. It is further suggested that the results of this analysis be used to aid in the costing evaluation of proposed AVS designs.

TABLE OF CONTENTS

	Page
1. INTRODUCTION	1-1
1.1 Background	1-1
1.2 Analysis Objectives	1-2
2. PROCEDURE	2-1
2.1 Major Assumptions	2-1
2.2 General Methodology	2-4
2.2.1 Delay Savings Computation	2-4
2.2.2 AVS Cost Guidelines	2-6
2.2.3 Sensitivity of Savings to Demand	2-7
3. ASSESSMENT OF AVS REDUCED STANDARDS BENEFITS	3-1
3.1 Maximum Potential Annual Delay Savings	3-1
3.2 Total Delay Savings	3-3
3.2.1 IFR Delay Savings of 3 nmi Versus Today's Standards	3-3
3.2.2 IFR Delay Savings of 2.5 nmi Standards Versus VAS Baseline	3-5
3.2.3 IFR Delay Savings of 2.0 nmi Compared to 2.5 nmi Standards	3-8
3.3 F&E Cost Guidelines	3-11
4. RESULTS AND RECOMMENDATIONS	4-1
4.1 Major Results	4-1
4.2 Topics for Further Research	4-1
4.3 Recommendations	4-3
APPENDIX A: DETAILS OF THE ANALYSIS	A-1
A.1 Capacity Calculations	A-1
A.2 Demand Forecasts	A-2
A.3 Delay Estimation	A-2
A.4 Delay Cost and Benefit Computations	A-3
APPENDIX B: INPUT DATA FOR FULL DEMAND ANALYSES	B-1

TABLE OF CONTENTS
(Concluded)

		Page
APPENDIX C:	DATA FOR LOWER DEMAND ANALYSIS OF 2.5 NMI SEPARATIONS	C-1
APPENDIX D:	DEMAND ADJUSTMENTS AND CAPACITIES USED TO COMPARE 2.0 AND 2.5 NMI SEPARATION STANDARDS	D-1
APPENDIX E:	REFERENCES	E-1

LIST OF ILLUSTRATIONS

		Page
TABLE A-1:	ANNUAL PERCENT IFR WEATHER AT TOP U.S. AIR CARRIER AIRPORTS	A-4
TABLE A-2:	AVERAGE 1976 OPERATING EXPENSE BY AIRCRAFT CLASS	A-5
TABLE B-1:	FORECASTED 1985 AND 1995 MIX DISTRIBUTIONS	B-2
TABLE B-2:	1985 IFR CAPACITIES IN OPERATIONS PER HOUR	B-3
TABLE B-3:	1995 IFR CAPACITIES IN OPERATIONS PER HOUR	B-5
TABLE B-4:	1985 AVERAGE DELAY ESTIMATES (MINUTES/OPERATIONS) FULL AVP-PROJECTED DEMANDS	B-7
TABLE B-5:	1995 AVERAGE DELAY ESTIMATES (MINUTES/OPERATIONS) FULL AVP-PROJECTED DEMANDS	B-8
TABLE C-1:	PREDICTED 1985 AND 1995 MIX DISTRIBUTIONS, AIR CARRIER AND AIR TAXI ONLY	C-2
TABLE C-2:	1985 IFR CAPACITIES BY CONFIGURATION, AIR CARRIER AND AIR TAXI ONLY	C-3
TABLE C-3:	1995 IFR CAPACITIES BY CONFIGURATION, AIR CARRIER AND AIR TAXI ONLY	C-5
TABLE C-4:	SUMMARY OF GENERAL AVIATION AND CAPACITY ADJUSTMENTS MADE TO PROJECTED 1985 DAILY OPERATIONS	C-8
TABLE C-5:	SUMMARY OF GENERAL AVIATION AND CAPACITY ADJUSTMENTS MADE TO PROJECTED 1995 DAILY OPERATIONS	C-9
TABLE C-6:	1985 PROJECTED AVERAGE DELAY ESTIMATES, AIR CARRIER AND AIR TAXI ONLY	C-10
TABLE C-7:	1995 PROJECTED AVERAGE DELAY ESTIMATES, AIR CARRIER AND AIR TAXI ONLY	C-11
TABLE D-1:	2.0 VERSUS 2.5 NMI STUDY, SUMMARY OF ADJUSTMENTS TO PROJECTED 1985 DAILY DEMAND	D-2
TABLE D-2:	2.0 VERSUS 2.5 NMI STUDY, SUMMARY OF ADJUSTMENTS TO PROJECTED 1995 DAILY DEMAND	D-3

LIST OF ILLUSTRATIONS
(Concluded)

		Page
TABLE D-3:	CAPACITIES USED FOR 2.0 VERSUS 2.5 NMI DEMAND SENSITIVITY STUDY	D-5
TABLE D-4:	AVERAGE DELAY PER OPERATION ESTIMATES, 2.0 VERSUS 2.5 NMI STUDY	D-7
FIGURE 2-1:	SELECTED IFR SEPARATION STANDARDS	2-2
FIGURE 2-2:	GENERAL METHODOLOGY	2-5
FIGURE 2-3:	RELATIONSHIP OF DEMAND AND DELAY	2-8
FIGURE 3-1:	MAXIMUM POTENTIAL ANNUAL DELAY SAVINGS AT TOP 20 AIRPORTS	3-2
FIGURE 3-2:	IFR DELAY SAVINGS OF 3.0 NMI STANDARDS VS. TODAY'S STANDARDS, FULL DEMAND	3-4
FIGURE 3-3:	IFR DELAY SAVINGS OF 3.0 NMI STANDARDS VS. TODAY'S STANDARDS, REDUCED DEMAND	3-6
FIGURE 3-4:	IFR DELAY SAVINGS OF 2.5 NMI STANDARDS VS. VAS BASELINE, FULL DEMAND	3-7
FIGURE 3-5:	IFR DELAY SAVINGS OF 2.5 NMI STANDARDS VS. VAS BASELINE, REDUCED DEMAND	3-9
FIGURE 3-6:	IFR DELAY SAVINGS OF 2.0 VS. 2.5 NMI MINIMUM STANDARDS, FULL DEMAND	3-10
FIGURE 3-7:	IFR DELAY SAVINGS OF 2.0 VS. 2.5 NMI MINIMUM STANDARDS, REDUCED DEMAND	3-12
FIGURE 3-8:	MAXIMUM F&E COSTS FOR EQUIPMENT TO PROVIDE 2.5 NMI MINIMUM STANDARDS (REDUCED DEMAND)	3-14

1. INTRODUCTION

1.1 Background

Air travel forecasts for the next decade indicate the requirement for additional capacity at many of the nation's airports, particularly under Instrument Meteorological Conditions (IMC). One traditional way to increase capacity has been by building new or expanding existing airport facilities. However, growing community resistance to that approach in combination with rising land acquisition and construction costs are forcing officials to look for alternate means of response. Another way to provide additional capacity is to reduce the longitudinal separation distances between aircraft on final approach. The major problem in achieving closer interaircraft spacings is the potential for a hazardous encounter between a trailing aircraft and the wake vortex shed by the preceding aircraft. Other potential constraints such as runway occupancy time and beacon garbling appear to be less difficult, at least from a technical viewpoint, than are the safety problems posed by wake vortices (Reference 1). Solving the vortex question stands out as a primary key to the realization of capacity increases through reduced longitudinal separation standards.

Research to date has resulted in Advanced Vortex System (AVS) concepts of two basic types. Vortex alleviation schemes propose to resolve the problem by altering the way in which the air flow patterns behave directly behind the wings. Ideas ranging from winglets to partially or fully extended landing gear are under investigation. Changing the spoiler deployment configuration has been identified as one of the more promising possibilities (Reference 2). The basic goal of changes in the flight configuration is to either inhibit formation of the vortical motion or else induce sufficient turbulence into the shed air streams as to promote rapid deterioration and subsequent breakup of the rotating mass within a relatively short distance (i.e., less than 2 nmi) from its generator (Reference 3). Should the airborne alleviation concepts prove infeasible, the second set of AVS ideas propose to space aircraft at the distances required to avoid probable vortex encounter. Since the necessary spacings would vary with wind and atmospheric stability conditions, successful application of the vortex avoidance concepts would require an airborne or ground-based ability to track, monitor, and perhaps predict vortex behavior.

Two generations of ground-based vortex avoidance systems are emerging from the FAA development program and should be briefly mentioned in order to complete the background for this analysis. The first is the Vortex Advisory System (VAS) which is currently installed at Chicago O'Hare International Airport. VAS operates by sampling surface wind magnitude and direction and then matching those measurements against criteria permitting minimum 3 nmi arrival separations (Reference 2). The air traffic controller is signalled via a "green light" indicator that spacings may be reduced. A shift to "red light" implies returning the spacings to today's 3/4/5/4/6 rules.* A dual (inner and outer) ellipse system providing hysteresis and a moving average of wind velocity are provided to prevent frequent fluctuations between standards. A recognized limitation of the VAS is the inability to predict wind conditions an increment of time into the future or to monitor atmospheric stability in addition to the wind vector. Incorporating these capabilities, the Wake Vortex Avoidance System (WVAS) is envisioned as the second generation, ground-based program able to not only read a more complete meteorological picture but also track and predict vortex motion and decay. When linked to the proposed ATC automated metering and spacing function, WVAS should permit replacing fixed arrival and departure standards with separations matched to prevailing wind and atmospheric stability conditions. The system also may offer capacity improvements in a manual ATC environment by providing controllers with a simplified set of reduced separation standards when conditions permit.

1.2 Analysis Objectives

A previous analysis, conducted for Chicago O'Hare, delineated significant capacity benefits from 3 nmi spacings as compared to maintaining today's arrival separation standards (Reference 4). This study builds upon that foundation by quantifying the delay reduction inherent to various sets of reduced longitudinal separation standards. Three groups of separation standards (3 nmi, 2.5 nmi, and 2.0 nmi minimum spacings) were adopted to represent the range of probable Advanced Vortex System capability. (Recall that the term Advanced Vortex System is defined as either an airborne alleviation or an air or ground-based vortex avoidance technology.) The major purpose of the effort was to permit delay savings comparisons to be conducted as a function of the selected spacing distances. The

*Strings of numbers such as 3/4/5/4/6 refer to separation minima in nautical miles permitted between large-large, heavy-heavy, heavy-large, large-small, and heavy-small pairings, respectively. Remaining combinations are governed by the large-large spacings.

research correspondingly was formatted into three steps that consider (1) today's versus VAS or 3 nmi rules, (2) VAS or 3 nmi versus 2.5 nmi minimum standards, and (3) 2.5 nmi versus 2.0 nmi minimum standards. The second major study objective involved developing a procedure from which rough cost guidelines could be derived to aid in the evaluation of future, proposed AVS designs. Although the first cut cost envelopes are directly applicable only to facilities and equipment outlays, the guidelines could also be used to aid in making decisions on the magnitude of research and development allocations for an AVS program.

2. PROCEDURE

A brief review of the general methodology is presented. Inherent to the discussion are a number of assumptions concerning the analysis time period, airport capacity calculations, demand forecasts, and other factors that have a direct influence on the study results.

2.1 Major Assumptions

Quantifying the time savings consequent to closer longitudinal separations required identifying terminal areas most likely to realize the major part of the benefits from an AVS program. The twenty airports handling the most air carrier operations in 1976 were selected as a reasonable data set. Viewed from a ground-based AVS standpoint, the busiest twenty facilities probably encompass those airports at which WVAS units would prove cost-effective. Similarly, airborne alleviation or avoidance systems could be expected to be most worthwhile in the more congested airspace typical of the nation's busier facilities.

Advanced Vortex Systems are only a general concept at the present time. It was hypothesized, however, that the required definition, development, and testing would be completed on a schedule such that an airborne or ground-based system could begin to benefit the nation's air users by 1985. A time period extending from the base year 1985 through the year 1995 was selected as a suitable time frame across which the benefit and equipment cost streams could be analyzed.

Four sets of longitudinal separation standards were selected to typify minimum spacings across the range of interest. The four groupings, shown in Figure 2-1, are applicable only to IFR weather conditions. Minimum required separation standards are not defined for VFR weather conditions. While Category I IFR weather is defined to be ceiling (feet) - visibility (nmi) conditions between 1000-3 and 200-1/2, IFR weather was assumed to be, for the purposes of this analysis, ceiling-visibility below 1500-3. This was necessitated by the availability of quantized weather data (Reference 12). Note that a small (S) aircraft is defined as weighing less than 12,500 lbs. (maximum certificated Gross Takeoff Weight (GTOW) while the large (L) category extends from 12,500 to 300,000 lbs. Heavy (H) aircraft such as DC-10's or B747's weigh in excess of 300,000 lbs (maximum GTOW). Set 1 of the selected standards corresponds to operations in practice at the present time. Although the major purpose of an AVS effort is to reduce the spacing distance between all lead-trail pairs, particular emphasis is directed at the larger 4,5, or 6 nmi separations currently used.

Arrival/Arrival (NMI).

Set 1 (Today's)

Lead \ Trail	S	L	H
S	3	3	3
L	4	3	3
H	6	5	4

Set 2 (VAS)

Lead \ Trail	S	L	H
S	3	3	3
L	3	3	3
H	4	3	3

Set 3 (AVS: 2.5 NMI Min.)

Lead \ Trail	S	L	H
S	2.5	2.5	2.5
L	3.0	2.5	2.5
H	3.5	3.0	2.5

Set 4 (AVS: 2.0 NMI Min.)

Lead \ Trail	S	L	H
S	2.0	2.0	2.0
L	2.5	2.0	2.0
H	3.0	2.5	2.0

Dep/Dep (SECS).

60/90/120
(For Sets 1 & 2)

60/60/90
(For Set 3)

60/60/60
(For Set 4)

FIGURE 2-1
SELECTED IFR SEPARATION STANDARDS

The second set of standards shown in Figure 2-1 correspond to the VAS program as was originally proposed. Primarily 3 nmi arrival-arrival spacings across-the-board, the VAS standards were assumed as available for the purposes of this study. Although an alleviation technique or improved ground-based monitoring procedure might prove more efficient or accurate, at least one system currently exists that promises to provide minimum spacings in the vicinity of set 2. Furthermore, system effectiveness data supplied by Transportation Systems Center (TSC) (Reference 5) indicated that VAS installations on an average across the airports of interest indicate favorable meteorological conditions for reduced spacings about forty percent of the time. A breakdown of VAS green/red light conditions for IFR conditions was not available. It was assumed that the overall 40% effectiveness of VAS is also applicable under IFR conditions. Based upon these facts, a VAS baseline scenario was postulated as using the VAS standards given in Figure 2-1 forty percent of the time and relying upon today's separations during the other sixty percent of the time. The delay consequences from other alternatives were compared against this VAS baseline system.

The remaining two groups of separation standards shown in Figure 2-1 were selected to typify separation rules in the vicinity of 2.5 nmi and 2.0 nmi, with an additional 0.5 nmi added to heavy-large and large-small pairings, and an additional 1.0 nmi added to the heavy-small pair. The two sets are consistent with the Airport Task Force efforts currently underway (Reference 6). Two other groups of standards, not given in Figure 2-1, also were included in the analysis. An alternative to Set 3 contained 2.5 nmi rather than 3.0 nmi for the L-S and H-L combinations. Similarly, the alternative to Set 4 used 2.0 nmi instead of 2.5 nmi for the L-S and H-L pairs. The research, completed with both sets of 2.5 nmi and 2.0 nmi standards, found such a small amount of difference between the delay results that only the consequences of Sets 3 and 4 will be discussed in this report. The AVS concepts hypothesized by the arrival-arrival standards of Figure 2-1 assume a complementary application to the departing aircraft stream. Departure-departure separations under today's operating environment require 120 seconds spacing between a heavy followed by a large or small aircraft, 90 seconds between two heavies, and 60 seconds between any other combination. These rules are denoted as 60/90/120 as illustrated on Figure 2-1. A reduction to 60/60/90 for departures was assumed to be provided by an AVS technology able to permit 2.5 nmi between arrivals and uniform 60/60/60 departure spacings under a 2.0 nmi AVS.

Other assumptions involving the dollar value of the delay minutes, estimating airport capacities etc. also were necessary to the study. However, those items are best detailed within a discussion of the analysis procedure in Appendix A.

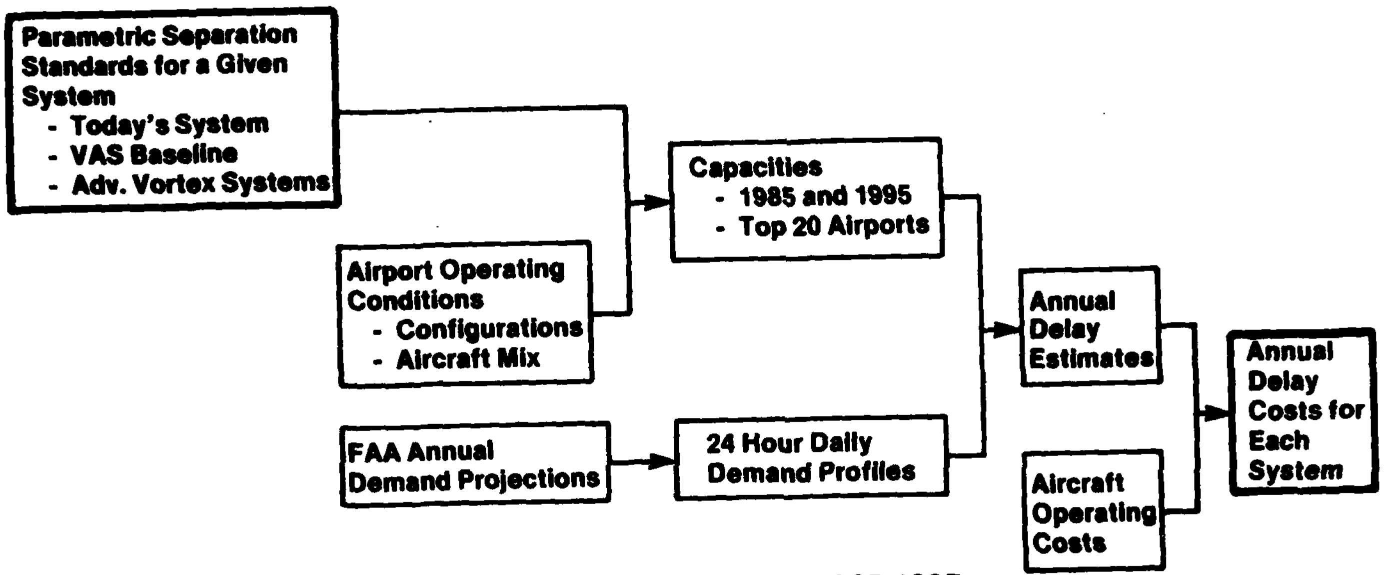
2.2 General Methodology

2.2.1 Delay Savings Computation

The process culminating in delay costs or conversely the benefits associated with closer spacings consisted of a four step computational procedure outlined in Figure 2-2. Several sets of IFR weather separation standards were selected, as previously discussed, to represent the range of AVS potential activity. Those separation groups, combined with information descriptive of each airport operating condition, permitted estimates of the throughput capacity for the top 20 facilities to be calculated.

The airport inputs consisted of the future mix of aircraft types projected to use each airport in 1985 and 1995 as well as representative runway configurations typifying each facility's IFR operations. Capacity values for each of the 20 airports in the two end years of the analysis time frame then were combined with forecasted demand profiles descriptive of each airports average 24 hour day for the two end years to provide delay per operation estimates. Creation of the required daily demand profiles was based upon current operation patterns in conjunction with annual demand projections. Those forecasts as well as the probable future aircraft mixes were supplied by the FAA's Office of Aviation Policy (AVP) (Reference 7,8). Details of the demand and capacity calculations are given as part of Appendix A.

Comparison between separation standards of the differences in IFR delays <u>on a per operation basis</u> found relatively small quantities of time at stake. Magnitudes on the order of one or two minutes per operation were typical. Such savings can only be economically worthwhile to factors where increments of savings can accrue. Those categories from an air travel viewpoint would be limited to flying (including flight and cabin crew, fuel and oil, and insurance) and to maintenance (burden, airframe, and engines) outlays. The savings would seldom be of appreciable influence on aircraft depreciation or rentals or to the typical passenger since small quantities of time seldom can be profitably utilized. Therefore, this study applied only



- For Each System, Annual Delay Costs for the Years 1985-1995 Are Discounted Back to 1985 to Give Total Delay Costs
- Delay Savings Benefit Is Then Calculated as the Difference of the Total Delay Costs of the Candidate Systems

FIGURE 2-2
GENERAL METHODOLOGY

aircraft flying and maintenance rates to the delay cost projections. The fuel savings realized by holding departures at the gate during periods of long delay were not included as idling consumption is small compared to airborne fuel use.

These delay cost factors, expressed in dollars per minute, permitted each airport's forecasted delay per operation to be converted to delay costs. The delay costs were calculated only for the two end years of the analysis period, however. Linear interpolation was used for the intermediate data points between 1985 and 1995. This procedure is an approximation of the actual nonlinear delay-demand relationship and the exponential growth of both demand and cost.

Finally, the annual delay costs characterizing each airport were summed over the twenty airports to provide the total within each year and each separation set. Establishment of the VAS baseline (40% VAS standards and 60% today's rules) permitted comparisons to be conducted between the baseline operating all of the time and the alternative of 2.5 nmi, or 2.0 nmi spacings in force some of the time with the VAS baseline picking up the remaining time. The benefits of closer spacings across the 1985 through 1995 period were discounted back to 1985 using a ten percent annual rate and are presented for a range of AVS effectiveness percentages. For a ground based system, percent effectiveness may be considered as the fraction of the time reduced separations are applicable. For a vortex alleviation system, it is reasonable to assume that the vortices are alleviated by equipped aircraft all the time. In this case, percent effectiveness can be a measure of the extent of fleet equipage for vortex alleviation. All delay benefits are given in 1976 dollar values which represented the latest information available on aircraft operating costs.

2.2.2 AVS Cost Guidelines

Determination of the potential delay savings permitted a balancing computation of the maximum amount that could be spent for facilities and equipment (F&E) in order to assure a breakeven AVS program. The resulting cost guidelines so specified include not only the cost of the AVS units but also the expense for any other ground or air-based equipment needed to provide the selected reduced separation standards. Additional assumptions stated that all F&E expense would occur in 1985 and be recovered across the 11 year span 1985 to 1995. No attempt was made to include the research and development component because the magnitude of that outlay has not been decided at this early stage in the program.

Operations and maintenance costs equalling, on an annual basis, ten percent of the F&E investment were included in the analysis. It should be mentioned that vortex avoidance units encompassing laser detectors or other complex devices may prove more maintenance intensive than the rate assumed in this study.

The O&M cost stream was reduced to the 1985 base year using a ten percent discount rate. Setting the F&E plus O&M cost equal to the potential delay savings benefits enabled the maximum F&E outlay to be calculated for each level of AVS effectiveness within each alternative. Such computations form a concept cost-effectiveness envelope useful to the evaluation of proposed AVS designs.

2.2.3 Sensitivity of Savings to Demand

The amount of delay experienced by airport users grows in a nonlinear manner as the total number of users requiring service rises. Figure 2-3 illustrates, in a general sense, the sharply increasing relationship between delay and demand. The plot also conceptualizes the impact closer interaircraft spacings have on delay at any particular demand level. It is recognized that each user class has a delay limit beyond which the lost time and expense become unacceptable. Delays longer than the cutoff threshold can be expected to force changes in an airport's overall amount of demand or the temporal pattern of that demand or both. Shown in Figure 2-3 is an example of the tradeoff between reducing delay and accepting more demand. Given today's system, the delay resulting from the full demand would be unacceptable to most users. Faced with this delay, some users would elect to use alternate facilities. As demand drops, the resulting delay also decreases, until an "acceptable" level of delay is reached. This occurs at demand level A, and the amount of unserviced demand is ΔD. The implementation of closer average spacings, such as VAS, would result in reduced delays. This in turn would allow the acceptance of part of the rejected demand, and demand would increase until the average delay once again reached the "acceptable" delay level, this time at demand level B. As progressively closer interarrival spacings are implemented, the delay first drops and then rises back up to the "acceptable" delay level as more of the previously rejected demand returns to the facility. In this example, when a 2.0 nmi system is implemented, the full projected demand can be serviced at an average delay level below the "acceptable" delay threshold.

By using in this analysis full projected demands (References 7 and 8) and modified (reduced, flattened, or both) demand profiles, conceptual upper and lower bounds are obtained for the

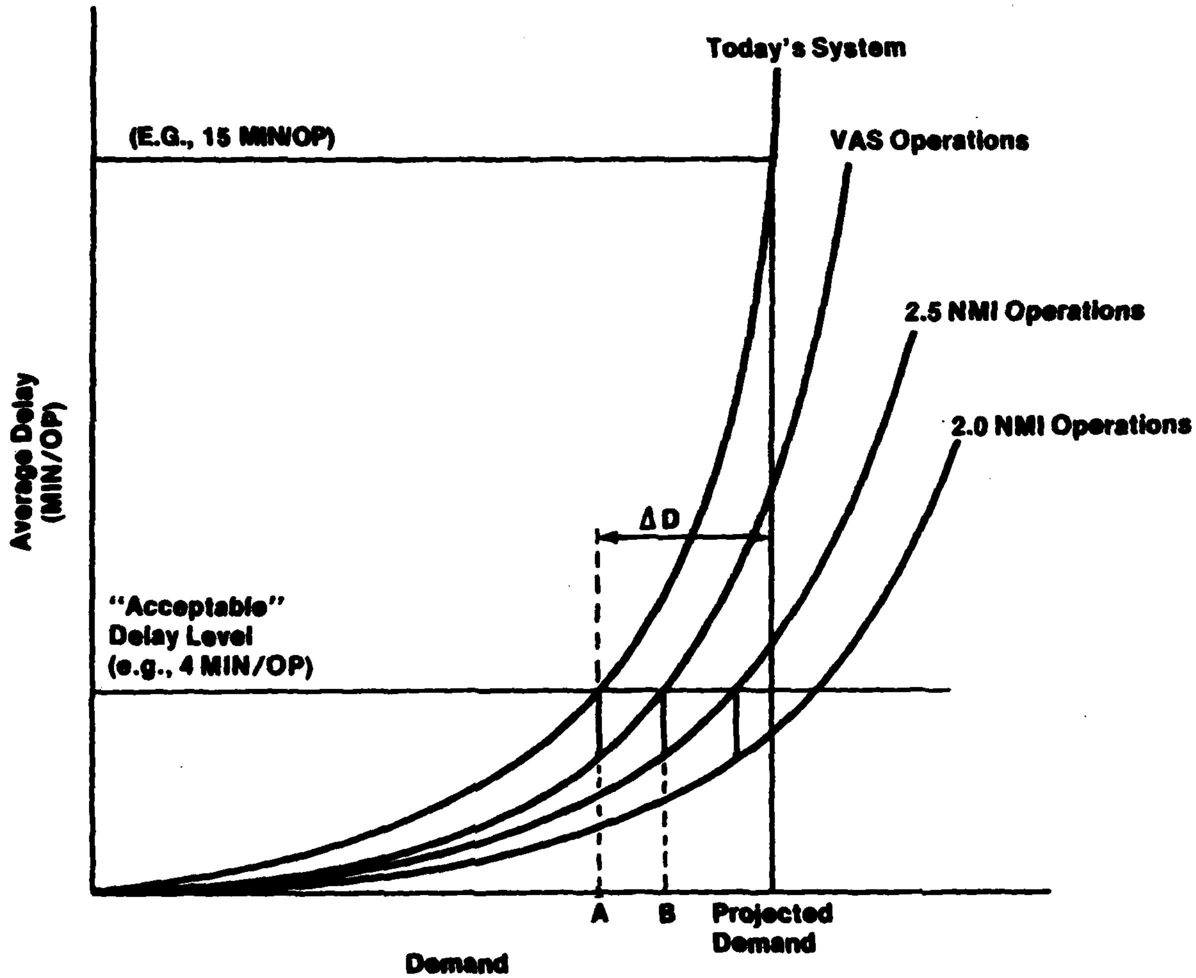


FIGURE 2-3
RELATIONSHIP OF DEMAND AND DELAY

value of delay reduction estimated to be attainable by the implementation of closer spacings. Full projected demands provide conceptual upper bounds since the cost of delay is greater than the perceived value of flying into or out of the particular facility as opposed to an alternate facility.

Modified demand profiles provide a conceptual lower bound since the resulting delay costs do not account for the value of the rejected demand. The ability to regard these numbers as bounds is dependent upon the assumption that the delays under the full demand scenarios are unacceptable while the delays under the modified demand scenarios are acceptable. With this in mind, the difference in delay costs between calculated delays and the "acceptable" delay level is an upper bound on the value of the rejected demand.

3. ASSESSMENT OF AVS REDUCED STANDARDS BENEFITS

Estimates of the potential delay savings inherent to closer interaircraft spacings are presented for three sets of separation standards. A measure of the maximum possible benefits, computed by assuming each separation set effective all of the time, is discussed first followed by more realistic comparisons incorporating the concept of AVS percent effectiveness. The delay savings offered by reduced longitudinal separations are shown to be substantial under a range of demand scenarios. An example application of the results demonstrates how a breakeven analysis to estimate facilities and equipment cost envelopes can be developed.

3.1 Maximum Potential Annual Delay Savings

Delay costs were determined for the two end years of the analysis period for today's rules, 3.0, 2.5, and 2.0 nmi minimum interarrival standards, as discussed in Chapter 2 and Appendix A. The actual delay numbers supporting the cost estimates are presented in Tables 4 and 5 of Appendix B as a function of the four separation groups. Linear interpolation then served to generate approximate costs for the years between 1985 and 1995.

Recall that a VAS or 3 nmi baseline was established as an operating scenario consisting of 40% VAS and 60% today's rules. Postulating that baseline allowed cost comparisons to be made between using a 3 nmi baseline system as present technology would provide or adopting some type of advanced vortex system effective a percentage of the time. An idea of the maximum delay cost difference between the reduced spacings and the VAS baseline is illustrated in Figure 3-1. Tabulated on an annual basis and expressed in 1976 dollars, the plot shows the delay savings that might be realized if the VAS baseline program were replaced by an advanced system that could provide reduced spacings through all IFR weather conditions. The current VAS baseline concept is shown as saving some 200 million dollars in 1990 as compared to maintaining today's operating rules. A potential delay savings up to 400 million dollars in 1990 appears possible if the effectiveness of a 3.0 nmi system could be increased toward 100 percent. Substantial additional savings beyond the maximum capable from 3.0 nmi spacings are available from 2.5 or 2.0 nmi separation conditions. Although 100 percent effectiveness is not operationally feasible, the plot indicates, as an example, a theoretical maximum 1990 delay savings of 1800 million dollars with 2.0 nmi spacings or 1200 million dollars given 2.5 nmi rules as compared to today's operations. It is clear that large savings over and above the 3.0 nmi potential

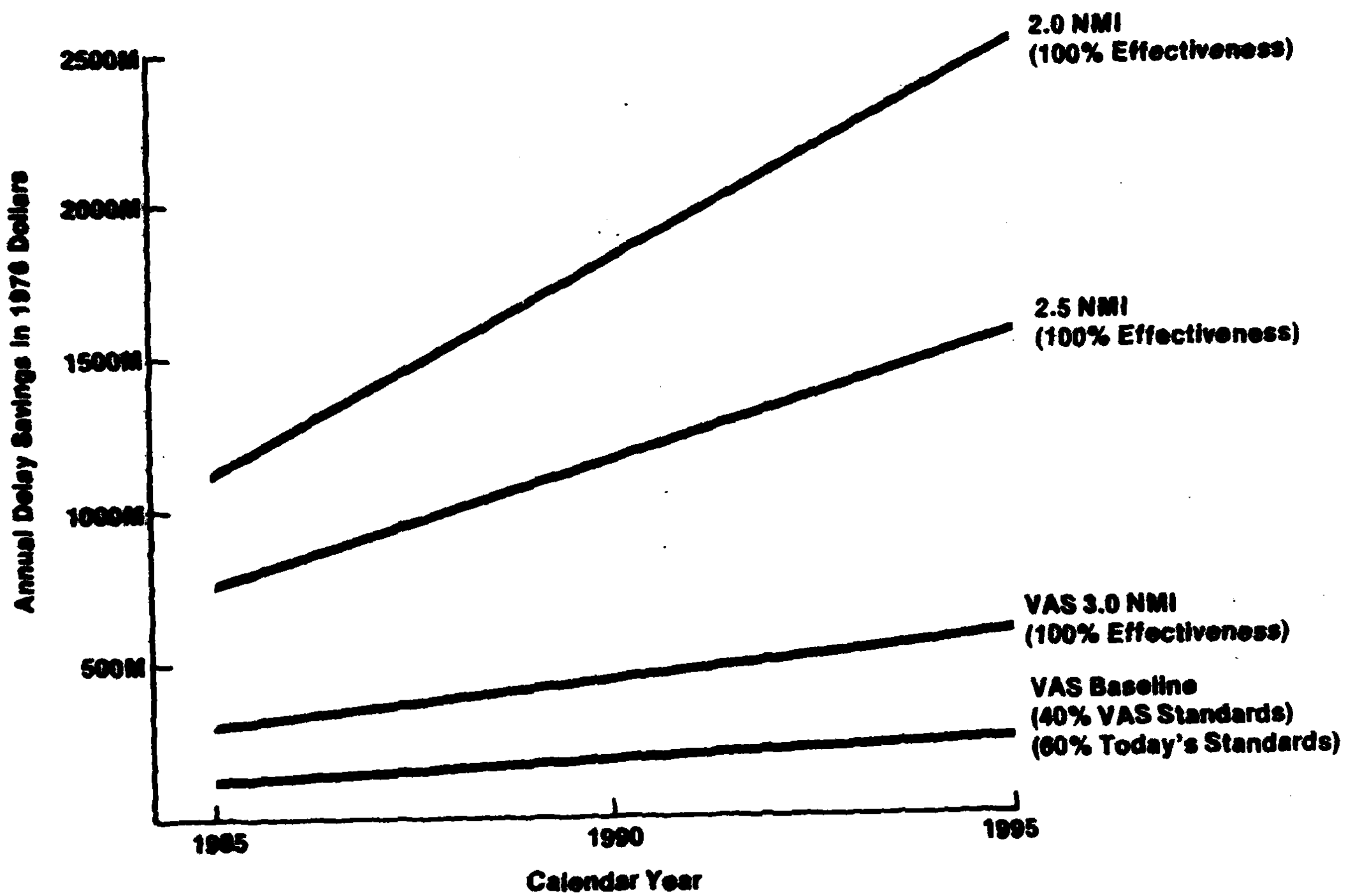


FIGURE 3-1
MAXIMUM POTENTIAL ANNUAL DELAY SAVINGS AT TOP 20 AIRPORTS

are possible from 2.0 nmi or 2.5 nmi systems effective less than full time. Note that these savings estimates are based upon accommodating all of the demand forecasted in each year for each facility.

3.2 Total Delay Savings

Assuming that AVS technology is able to assure reduced spacings 100 percent of the time during IFR conditions probably is unreasonably optimistic. A more realistic approach is to examine the impact on savings over a range of system effectiveness. The analysis is further aided by collapsing the benefit stream extending from 1985 through 1995 back to a base year, thus enabling discussion of an alternative's total delay savings. A ten percent rate was used to discount the annual delay savings contributions into the 1985 base year chosen for this study.

3.2.1 IFR Delay Savings of 3 nmi Versus Today's Standards

This part of the analysis addressed the potential benefit of reducing arrival-arrival longitudinal separations to a minimum of 3.0 nmi as previously discussed in Figure 2-1. The alternative assumed for this comparison was the option of simply extending today's operating procedures through 1995. Based upon the demand growth forecast by AVP (References 7,8), Figure 3-2 presents the potential delay reduction benefits a 3 nmi vortex avoidance or alleviation system might provide to as many as the top 20 air carrier airports. The estimated savings, although including only flying and maintenance costs, appear to be quite substantial. The current VAS system, for example, is anticipated as enabling 3 nmi spacings an average of 40 percent of the time. Such a capability shows promise of saving over a billion dollars across the eleven year analysis period assuming the projected demands actually occur and the present day hourly pattern of that demand is maintained.

It should be mentioned that average delay estimates computed for several airports were very large ($>$ 20 minutes per operation) when analyzed under either today's or 3 nmi spacings as Table B-5 indicates. Some shifting in demand magnitude or hourly pattern might reasonably be expected in response to the economic inefficiency of lost or wasted time. An indication of the sensitivity of the delay savings to changes in the demand was obtained by recalculating airport capacities and delays using lower demand totals and modified daily profiles.

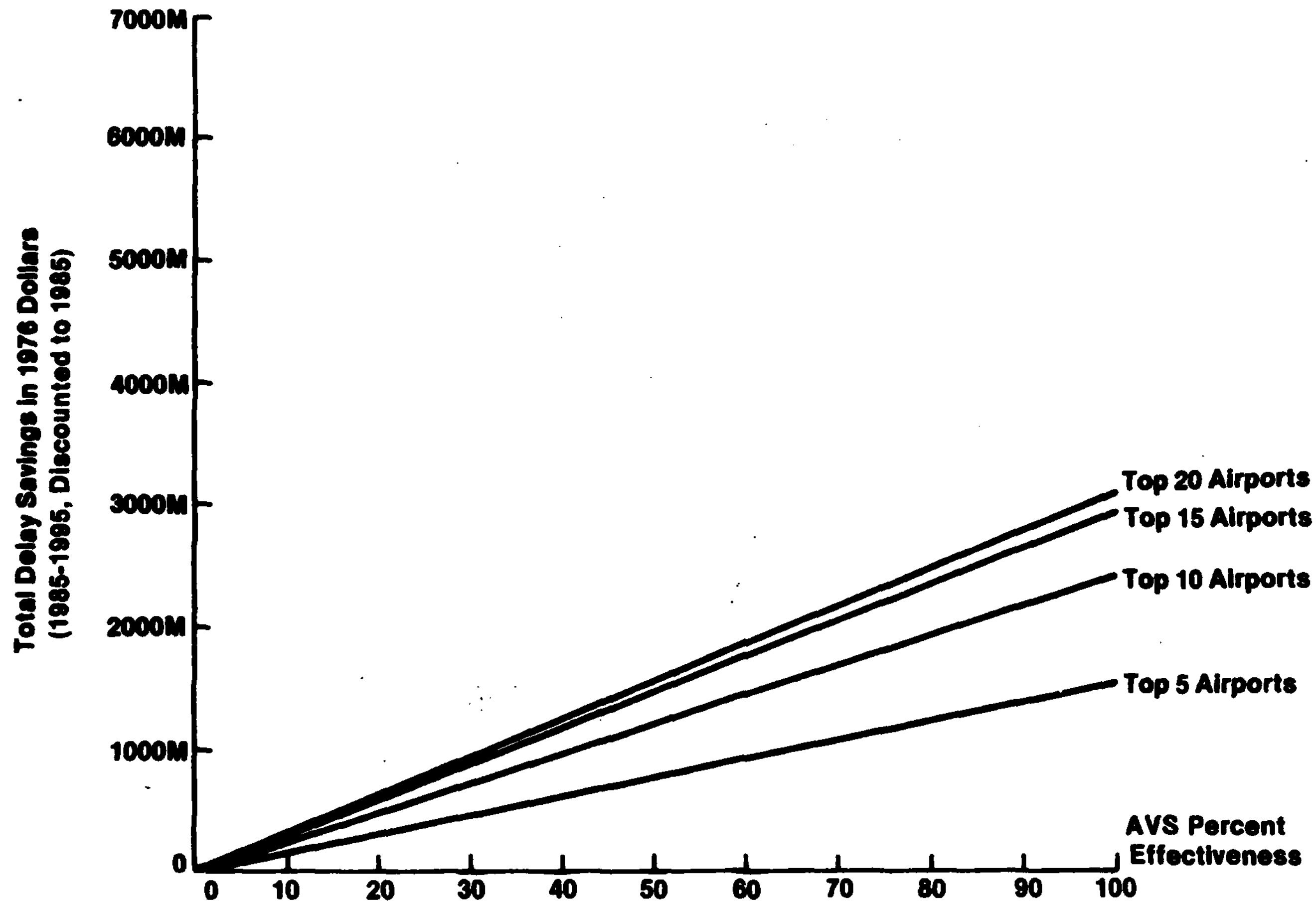


FIGURE 3-2
IFR DELAY SAVINGS OF 3.0 NMI STANDARDS
VS. TODAY'S STANDARDS, FULL DEMAND

The demand alteration process was based upon two assumptions. First, as delays grow, shifts will occur in the demand schedule, i.e., people will be willing to arrive earlier or later than their actual preferred time. Secondly, it is possible that some users, faced with long delays and IFR weather, may elect to either not fly at all or else will divert to suitably equipped reliever airports in the vicinity. Given the equal importance but greater flexibility of general aviation activity, this analysis assumed that this class of users would choose to operate into less congested, more easily accessed reliever airports during large delay periods. Demand at the crowded major airports then would consist primarily of scheduled air carrier and air taxi users. Capacities for each of the 30 runway configurations for the two years and four separation sets were computed using the analogous air carrier plus air taxi aircraft mixes. Tables in Appendix C contain the mix and capacity data for each facility. Note that removal of the general aviation demand segment only served as one way of lowering the overall demand magnitudes as required for this analysis. In reality, it is more likely that some GA users would remain and some air taxi or even air carrier flights would elect to divert.

Removing the general aviation component lowered the overall total demand but did not change the shape of the patterns of hourly use. The 1985 and 1995 daily demand profiles, projected for each airport, were subjected to further adjustments by flattening peak periods and shifting users to off-peak hours. Details of the demand adjustment process are presented in Appendix C. That Appendix also contains tables of the resulting average delay per operation estimates produced by the MIT model processing the adjusted capacity values and demand profiles.

The net output from this procedure was conservative estimates of the potential delay reduction benefits likely from 3.0 nmi separations rather than today's rules. Figure 3-3 summarizes the delay savings projected to occur given the above reduced demand scenario. Although significantly less than estimated for the full demand forecast, the savings remain very substantial.

3.2.2 IFR Delay Savings of 2.5 nmi Standards Versus VAS Baseline

The potential delay savings characterizing a 2.5 nmi AVS concept are delineated in Figure 3-4. The results are derived from a comparison between the delay costs of a VAS baseline program and

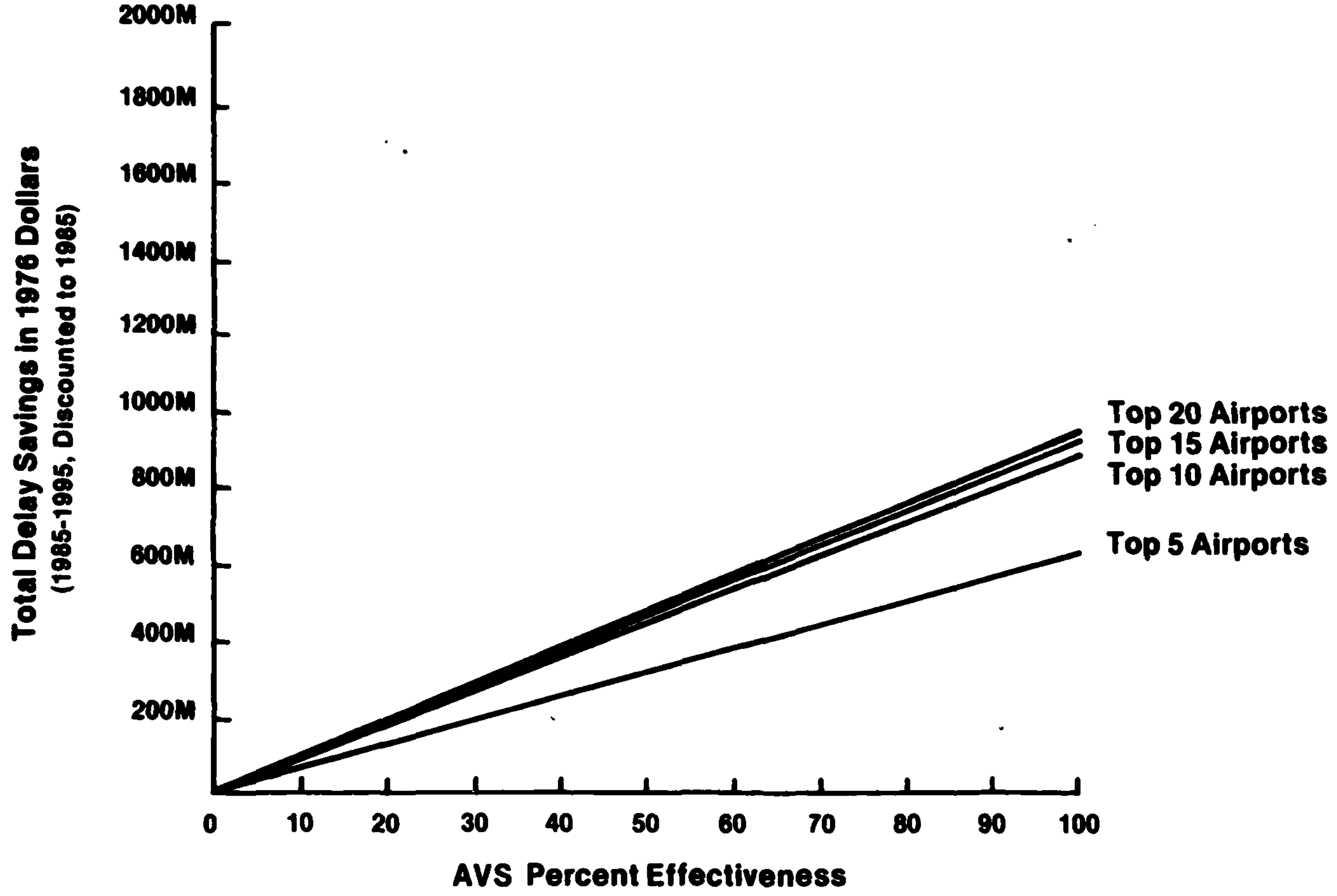


FIGURE 3-3
IFR DELAY SAVINGS OF 3.0 NMI STANDARDS
VS. TODAY'S STANDARDS, REDUCED DEMAND

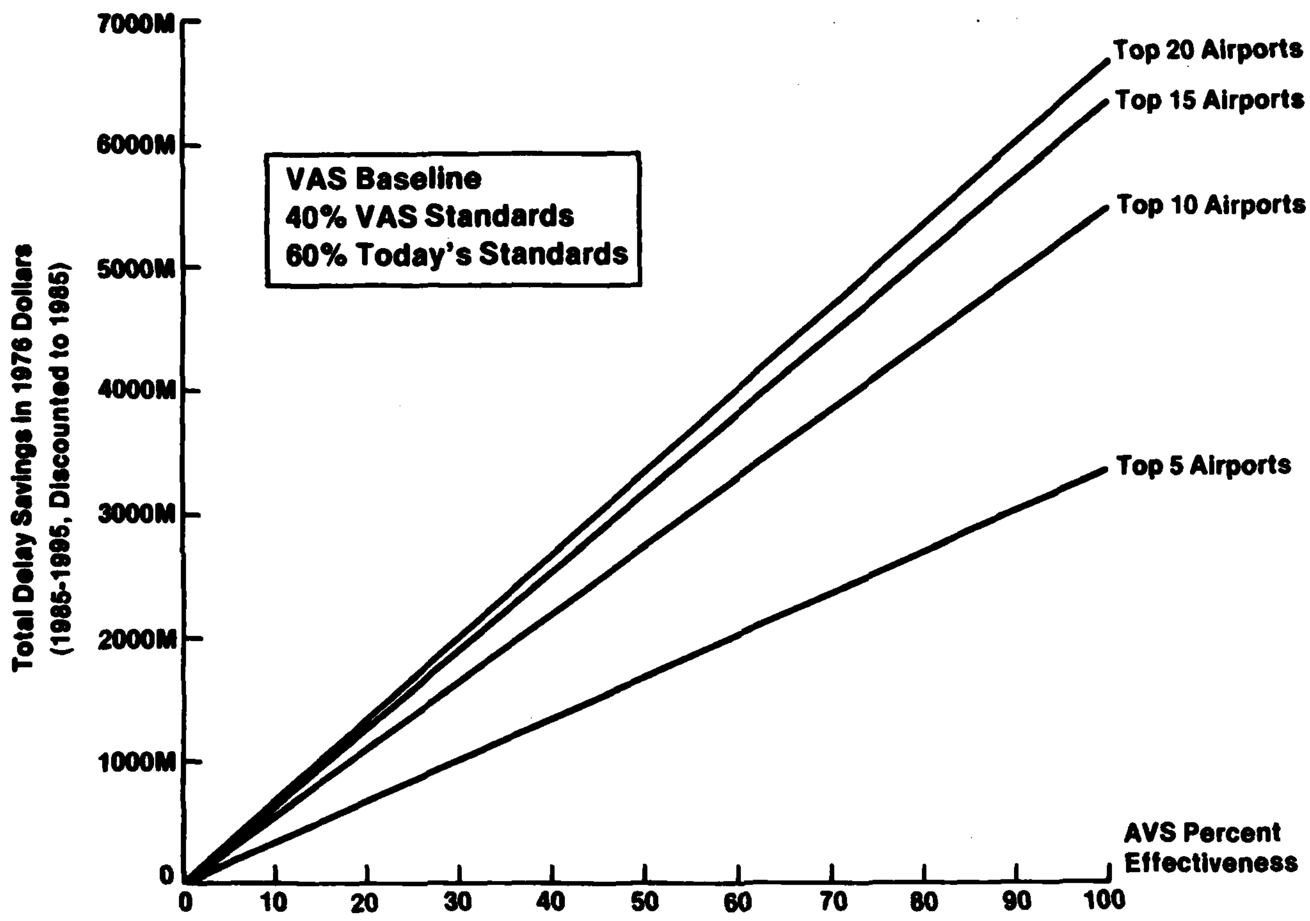


FIGURE 3-4
IFR DELAY SAVINGS OF 2.5 NMI STANDARDS
VS. VAS BASELINE, FULL DEMAND

an alternative composed of 2.5 nmi separations a percentage of the time and the VAS baseline picking up the remaining amount of time. The results are founded upon projected demand growth applied to present day user patterns. The subsequent high average delays at some airports cause very large forecasted total delay savings as the plot shows. Projected benefits for the top 20 airports are in the vicinity of four billion dollars for a given vortex system effective 60 percent of the time.

The demand sensitivity technique previously applied to the comparison of 3.0 nmi separations and today's rules was used again to assess the effect of less-than-projected demand growth on the estimated 2.5 nmi versus VAS baseline delay savings. Details of the adjustment process are discussed in Appendix C.

Reference to Figure 3-5 indicates a significant drop in the amount of projected total delay savings but the overall size of the benefits continues to be very worthwhile. Continuing with the 60 percent AVS example, anticipated savings for the top 20 airports exceed 800 million dollars across the eleven year analysis time period. The graph also indicates decreasing cost effectiveness as the number of airports included within the AVS program rises. The important point to be emphasized is the magnitude of the delay benefits possible from reduced separations across a range of demand growth scenarios.

3.2.3 IFR Delay Savings of 2.0 nmi Compared to 2.5 nmi Standards

Quantification of the delay savings possible from 2.0 nmi separations relative to a 2.5 nmi minimum spacing environment followed an analysis procedure very similar to the previous discussion. An upper bound on the possible delay benefits was derived by examining the AVP-provided demand totals as applied to present day hourly user profiles. More conservative, lower estimates were then supplied by altering the demand profiles according to a set of heuristic rules.

The actual savings were computed by taking the difference between two alternatives; one corresponding to 2.5 nmi and the other to 2.0 nmi rules. The AVS standards were hypothesized to have the same percentage effectiveness within each alternative. The VAS baseline was assumed to pick up the time periods not covered by the AVS alternatives.

Reviewing Figure 3-6 indicates that 2.0 nmi separation standards have the potential to provide considerable savings beyond those inherent to 2.5 nmi spacings. For example, based upon the full

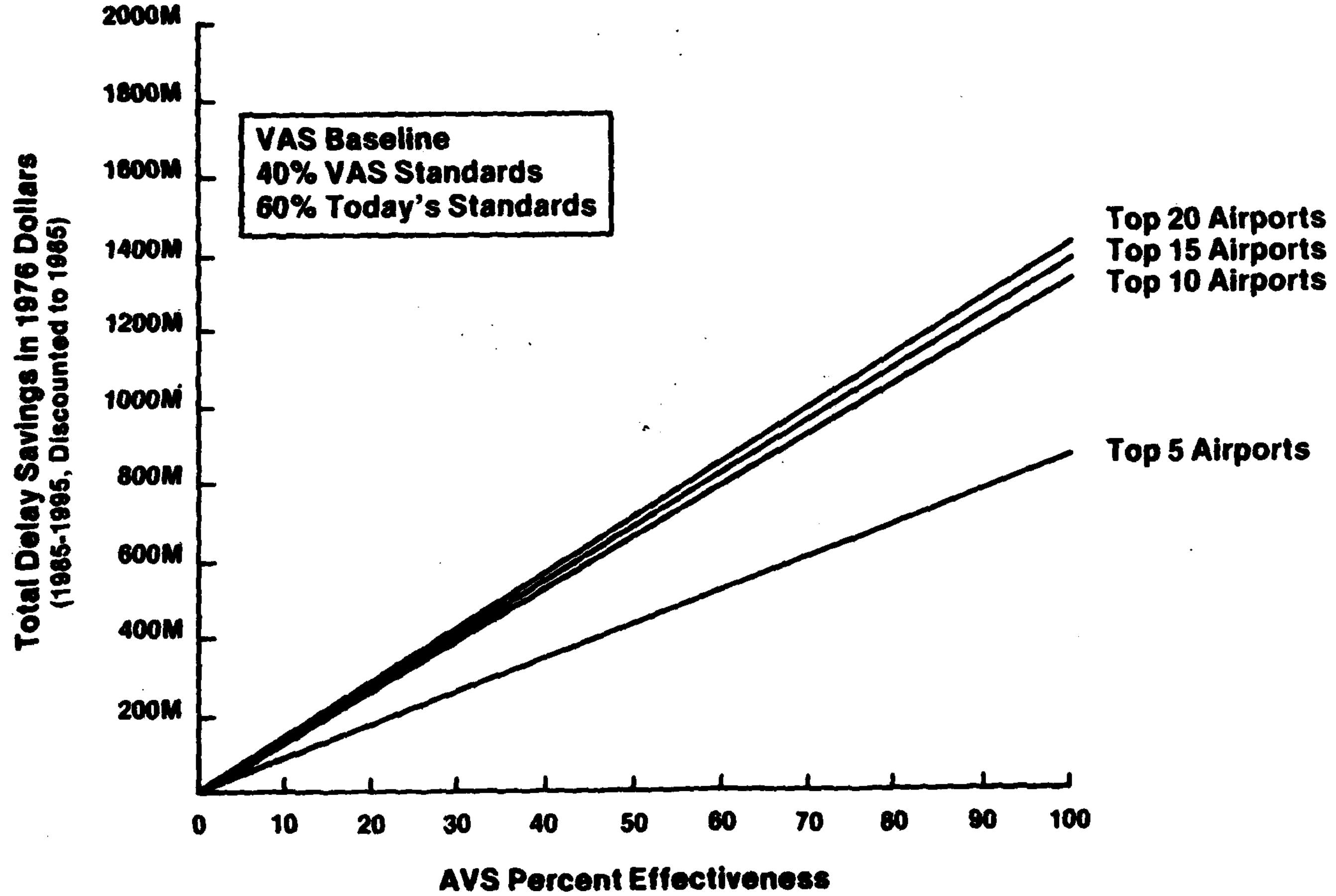


FIGURE 3-5
IFR DELAY SAVINGS OF 2.5 NMI STANDARDS
VS. BASELINE, REDUCED DEMAND

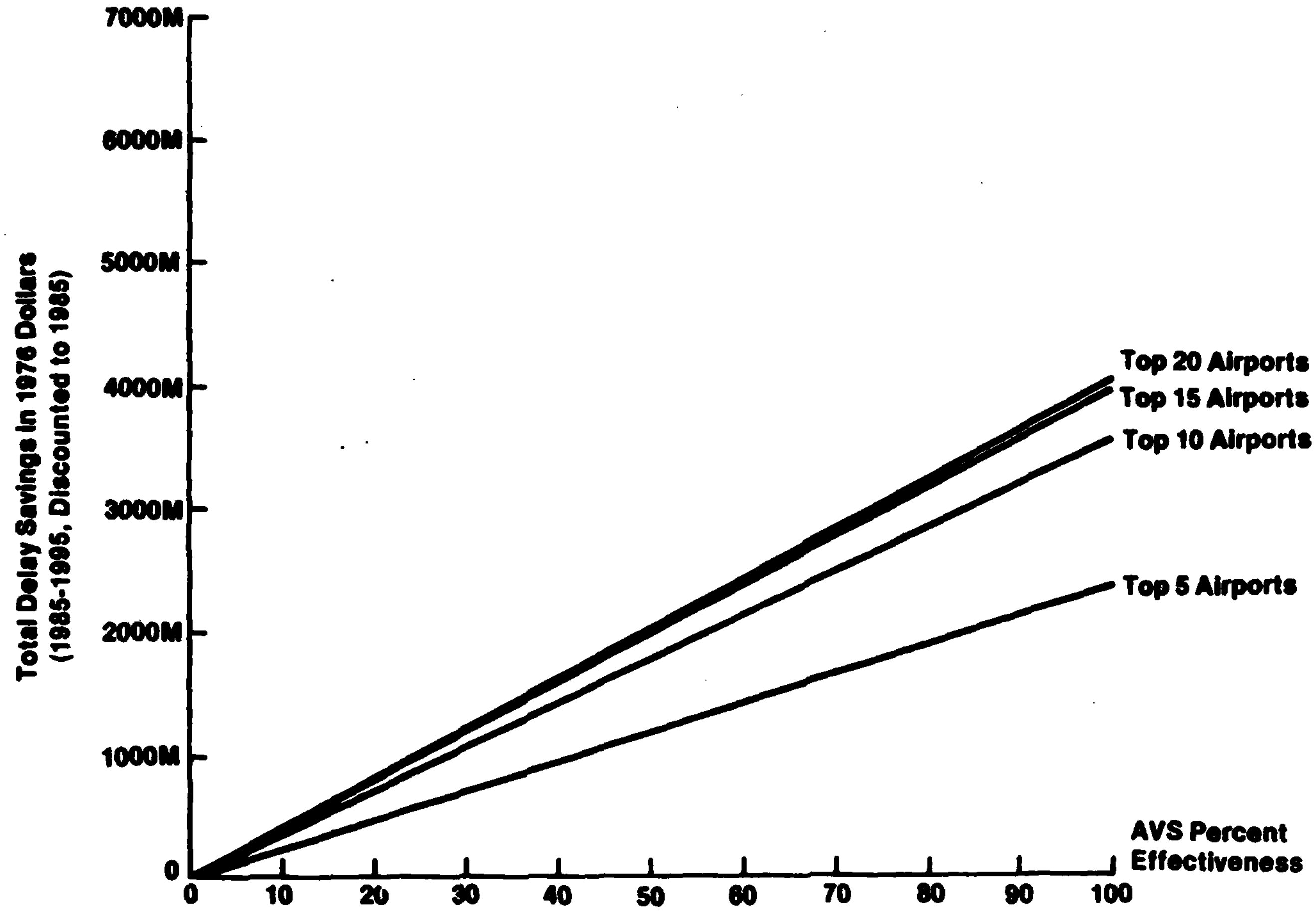


FIGURE 3-6
IFR DELAY SAVINGS OF 2.0 NMI VS. 2.5 NMI
MINIMUM STANDARDS, FULL DEMAND

demand projections, a 60 percent effective AVS offering 2.0 nmi between arrivals rather than 2.5 nmi could save approximately $2.5 billion at the top 20 airports.

The demand alteration process used to facilitate the determination of more conservative savings estimates followed the same general concept as used in the previous two comparisons. Available hourly capacity was assumed to be that corresponding to a 2.5 nmi separations environment. The greater capacity, in turn, permitted profiles consisting of all three demand components, i.e., air carrier, air taxi, and general aviation, to be considered. Forecasted demand was fitted via peak flattening to the vicinity of each airport's available capacity. The projected demand was accommodated in all but a few cases through this demand shifting process. Details of the procedure as well as capacity and delay tables are located in Appendix D. Delay estimates based upon less-peaked profiles were utilized to provide a lower estimate of the potential savings associated with 2.0 nmi standards. Figure 3-7 summarizes the net result of the demand sensitivity study. Delay savings benefits have been reduced roughly by half as a result of the peak flattening process. However, as was exemplified by the previous 3.0 and 2.5 nmi efforts, significant potential delay savings remain despite a set of radically different demand inputs.

3.3 F&E Cost Guidelines

Knowledge of the potential AVS benefits permitted a balancing first cut calculation of the permissible equipment costs in order to assure a cost-effective program. Only facilities and equipment (F&E) and operations and maintenance (O&M) outlays were considered as the size of the needed R&D effort has yet to be defined. All F&E expense was assumed to occur in 1985 and to be recovered across the eleven year span 1985 to 1995. Annual O&M expenditures were set equal to ten percent of the initial F&E outlay. The O&M cost stream was discounted back to its 1985 value using a ten percent discount rate.

The results of solving the cost-equals-benefits equation will necessarily vary with the AVS concept and aviation demand level. Simply as an example, the maximum F&E investment for the 2.5 nmi versus VAS baseline case under the reduced demand scenario is presented in Figure 3-8 as a function of AVS percent effectiveness. The plot gives a rough measure of the maximum F&E amount that could be expended on the complete package of equipment needed to provide 2.5 nmi minimum interarrival

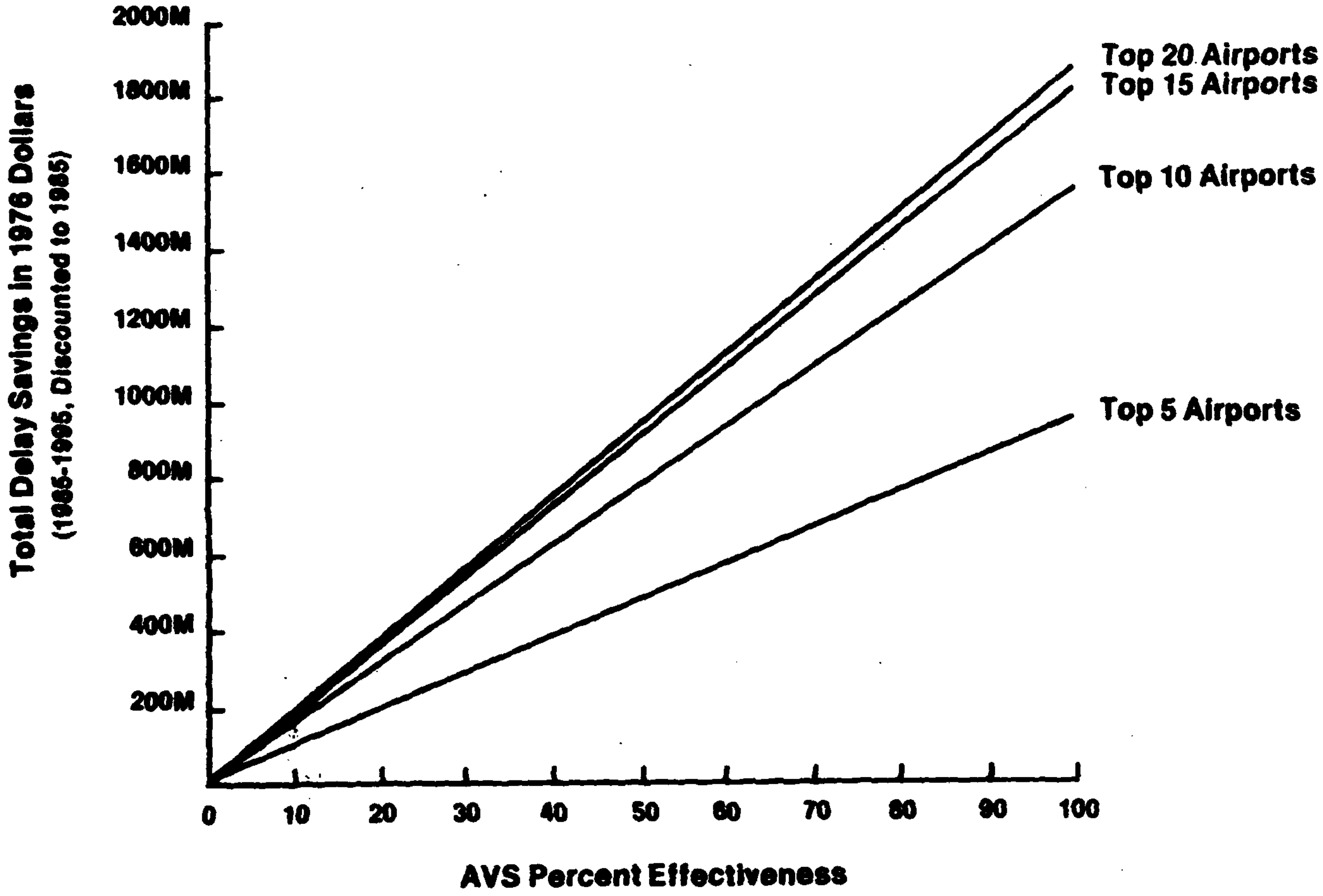


FIGURE 3-7
IFR DELAY SAVINGS OF 2.0 NMI VS. 2.5 NMI
MINIMUM STANDARDS, REDUCED DEMAND

capability. Some portion of that equipment would be individual AVS units. Roughly $350 million (in 1976 dollars) could be spent on the reduced spacings equipment needed across the top 20 airports if in return 2.5 nmi standards would be available 40 percent of the time. Diminishing cost-effectiveness is demonstrated as the AVS program is extended toward the less busy of these twenty airports.

The F&E cost envelopes, as demonstrated by Figure 3-8, should aid in the cost-effectiveness evaluation of proposed AVS designs. Extending the above example may serve to illustrate the application of the F&E information. Assume an AVS concept able to provide 2.5 nmi separations with a 60 percent effectiveness. Across the top 20 airports, Figure 3-8 indicates approximately 500 million dollars available for the F&E costs associated with all of the needed reduced spacings equipment. Assume further that half of that outlay must be assigned to non-AVS equipment, perhaps an automated metering and spacing function for example. Therefore, even under a reduced demand growth scenario, some 250 million dollars (1976$) would be available to cover AVS facilities & equipment expenses at the busiest 20 air carrier faciliites.

The proposed vortex concept will be either an airborne or ground-based system. Costs for an airborne AVS could reasonably be expected to be allocated across the air carrier fleet. Assuming 3000 jet aircraft implies the availability of approximately 80,000 dollars per aircraft at the breakeven costs-equal-benefits point. Costs for a ground-based system, on the other hand, might be allocated to the airports involved. Suppose the suggested design requires installing an AVS unit on each runway currently possessing an ILS approach aid. Under that rule, the top 20 airports would require roughly 80 AVS installations. Splitting $250 million across 80 units implies about $3 million per unit under breakeven conditions. Similar examples can be generated by setting costs equal to delay savings for any other demand conditions and AVS characteristics. Such costing guidelines should serve as useful aids during considerations of proposed AVS designs.

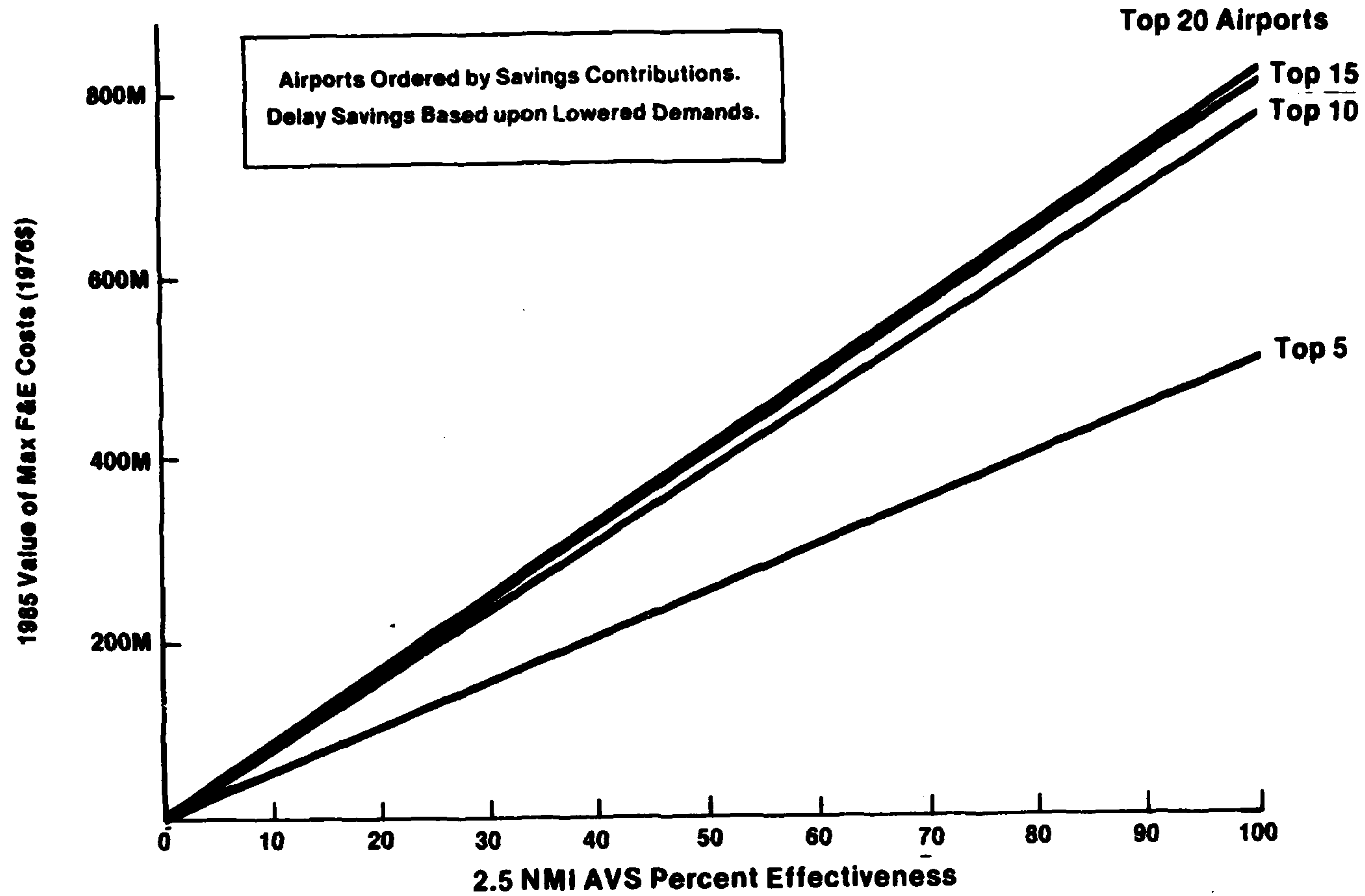


FIGURE 3-8
MAXIMUM F&E COSTS FOR EQUIPMENT TO PROVIDE
2.5 NMI MINIMUM SEPARATIONS (REDUCED DEMAND)

4. RESULTS AND RECOMMENDATIONS

4.1 Major Results

Significant runway-related delay savings appear to be available from the reduced arrival and departure separations characterizing the Advanced Vortex System concept. The benefits are sufficiently large as to warrant a substantial research and development program designed to convert the current general ideas into cost-effective ATC hardware.

Conducted in a step-wise fashion, this study examined the potential benefits from a delay reduction standpoint of 3.0 nmi, 2.5 nmi, and 2.0 nmi minimum arrival standards. All three sets were analyzed under two scenarios of projected demand. Very large delay savings due to each successive step in reduced spacings were found even under the reduced, conservative demand assumptions. The 1985 value of the 1985-1995 benefits for the top 20 air carrier airports operating with an AVS providing 2.5 nmi spacings 60 percent of the time, for example, were estimated to be in excess of $800 million given reduced demand and about $4000 million with the AVP-projected full demands. Savings such as this example were computed by comparing the AVS alternative against a full time baseline composed of 3 nmi standards 40 percent and today's spacings the remaining 60 percent of the time.

An additional contribution of the analysis was the foundation of the procedure for developing overall costing guidelines that can aid in evaluating proposed AVS designs. Estimates of the amounts which could be spent for reduced spacings equipment within a cost-effective program can be calculated from a cost-equals-benefit equation. Several assumptions involving discounting the O&M cost stream back to 1985, recovering the F&E investment, etc. are necessary but the net result is a series of relationships expressing the maximum F&E outlay as a function of AVS percent effectiveness and various groupings of airports. An example using a hypothesized AVS concept illustrated the costing guidelines development procedure. Formulation of appropriate assumptions enables guidelines to be specified that are applicable to airborne or ground-based AVS concepts.

4.2 Topics for Further Research

This study explored the possible delay advantages characteristic of arrival and departure separations providing closer interaircraft spacings than those inherent in today's rules.

However, a number of additional economic, technical, and operational questions must be addressed as part of future AVS development. Several examples of these questions may be postulated.

The overlying major economic topic that must be continually weighed concerns the estimated cost and performance of each proposed AVS concept. It is suggested that the delay benefit results produced by this study be utilized to aid in the definition of economically sound concepts.

Technical aspects to be considered cover a broad range. Can the same type of AVS device, for instance, be used to aid not only arrivals but also departures? This study assumed some reduction in departure-departure separations corresponding to the closer interarrival spacings. A second question concerns the upper, practical limit on AVS effectiveness for ground based systems. Recognized as airport-dependent, net effectiveness will result from the influence of three factors. First of all, weather conditions at a facility will permit using a particular set of standards only some percentage of the time. Secondly, the AVS will not operate as an ideal system. Some of the opportunities during which a desired set of separations could have been applied may not be properly recognized by the less than perfect equipment. Thus, the ideal effectiveness may be reduced by some amount due to system imperfections. Finally, the air traffic control system cannot be expected to respond by reconfiguring arrival and departure spacings in order to take advantage of every available reduced separations opportunity. The minimum length of time for green light conditions to be effectively utilized can be expected to be inversely dependent upon the amount of ATC automation and to the amount of advanced warning provided by the AVS prediction algorithm. A manual system and a short AVS look-ahead time will result in controllers using only those reduced spacings windows that appear to promise a lengthy existence. The net impact of these three factors may be a practical effectiveness for reduced spacings possibly much less than the desirable high percentages.

A third technical question of some significance concerns the coverage capabilities of a ground-based AVS. The amount of lateral and longitudinal (with respect to the threshold) monitoring capability will directly affect the ability of the aircraft stream to realize the full advantage of each separation set.

The overriding technical aspect for an airborne alleviation concept involves the means by which vortices can either be prevented from occurring or else forced to decay rapidly after creation. Will a certain flight configuration successful on a B-747, for example, work equally well on a DC-10 or L-1011? Alleviation techniques also may be a function of ambient wind and atmospheric stability conditions.

From an operational viewpoint, considerable attention must be devoted to the procedure for transitioning between separation standards. The technique for safely switching from 2.0 nmi spacings back to today's rules, for example, must be developed in detail. Ideally and perhaps necessarily, the amount of time needed to effect a transition between standards will determine the length of the forecast provided by the AVS prediction capability. An additional design constraint may be the amount of monitoring coverage area required to be provided in order to satisfy the minimum needs of the transitioning maneuvers.

4.3 Recommendations

Development of AVS capability is a key element to the ultimate achievement of standards for reduced separations in the vicinity of 2.0 or 2.5 nmi. It is recognized, however, that other E&D features such as automated metering and spacing may prove necessary to permit full realization of the potential delay benefits. Based upon the magnitude of the operating savings reduced separations appear to offer, it is recommended that the development of AVS be pursued as a priority research and development item. It is further suggested that the results of this analysis be used to aid in the costing evaluation of proposed AVS designs.

APPENDIX A

DETAILS OF THE ANALYSIS

The four step process used to compute delay savings briefly was discussed in Chapter 2. This appendix supplies additional details supporting the computational procedure.

A.1 Capacity Calculations

Adoption of four sets of IFR separation standards, shown in Figure 2-1, provided one of the inputs required to estimate capacity values for the twenty air carrier airports chosen as a data set for this analysis. The other needed inputs were the mix of aircraft (% small, large, and heavy) forecast for each facility in 1985 and 1995 and the typical runway configurations used at each airport during IFR weather conditions.

Selection of the representative arrival and departure runway combinations followed one of three possible paths. A single configuration proved sufficient to model a number of airports. Other facilities, such as Boston Logan or Chicago O'Hare, required several different runway set-ups to adequately describe operations under various IFR weather and demand situations. Historical runway configuration utilization data were available for those airports. A third subset of airports, for which runway utilization data were not easily available, were analyzed using two configurations; one representing the high and the other the low side of that facility's capacity regime. The need, in some cases, to model more than one configuration per airport converted the 20 airports under consideration to a total of 30 configurations. Later, after delay values had been computed, the 30 configurations were collapsed back to 20 airports with the aid of utilization data. For those airports for which no utilization estimate was available, weighting factors of 75 and 25 percent were used for high and low capacity configurations, respectively.

Projections of the future types of aircraft by weight class for each airport were based upon 1985 and 1995 operations data supplied by FAA's Office of Aviation Policy (AVP) (References 7, 8). Air carrier, air taxi and general aviation served to categorize future operations. Air carrier equipment operations were obtained directly from Reference 8. Air taxi users were assumed to consist of 25 percent small and 75 percent large aircraft. All general aviation aircraft were assigned to the small aircraft category.

Capacities, expressed in operations per hour, were determined for each configuration in the two analysis years operating under each of the four separation sets. The estimates were calculated with the aid of an analytical model developed within MITRE (Reference 9). It is possible that later studies, utilizing a precise definition of AVS and requiring more accurate numbers on an airport-by-airport basis, may find it advantageous to rely on more costly simulation routines. However, for the requirements of this analysis a fast, inexpensive analytical algorithm proved adequate.

A.2 Demand Forecasts

The amount of delay experienced by the average user depends not only on the sheer magnitude of the total demand but also varies with the particular distribution of the demand throughout the day in relation to the capacity available. Twenty-four hour daily demand profiles for each airport in the years 1985 and 1995 were calculated by expanding the present (1976) temporal traffic patterns, available from Reference 10, by the ratio of projected future total demand to that in 1976. The daily demand used was the projected annual operations divided by 365, and therefore represents the average day. Total projected demand amounts were provided by Reference 7. This process contained an implicit assumption that the busiest general aviation activity periods correspond to the commercial peak times. Although the validity of that contention varies across the airports, it is believed not to be a serious source of error at this level of analysis. Additional adjustments to the postulated demand patterns were completed in order to examine the sensitivity of the delay savings to changes in demand. Those alterations are discussed in Appendices C and D.

A.3 Delay Estimation

Another analytical model, the MIT "DELAYS" Model (Reference 11), processed the projected capacities and demands to derive average delays expressed in minutes per operation. It was desired in this study to consider only delay magnitudes congruent with the amount of IFR weather nominally characteristic at each facility. The exclusion of VFR periods is based on the assumption that an AVS, as currently envisioned, will not be able to significantly improve good weather traffic flows. The delay estimates produced by the MIT algorithm correspond to continuous 24 hour IFR conditions. Thus aircraft queues in the model may build further and resulting average delays be longer than would occur in reality. Although the 24 hour average delays were reduced by the percent IFR weather at each facility

(Reference 12), the values may be somewhat larger than those which would have been calculated if a much more time consuming and expensive simulation procedure had been used. It is felt that this acknowledged source of error was balanced out by intentionally utilizing conservative demand estimates. The IFR weather percentages used to reduce the delay values are given in Table A-1.

A.4 Delay Cost and Benefit Computations

Based upon the small amount of delay difference between separation standards on a per operation basis, only flying and maintenance cost factors were applied to convert minutes of delay to dollar values. Flying costs include flight and cabin crew, fuel and oil, and insurance while maintenance expense covers burden, airframe, and engines. Aircraft depreciation, aircraft rentals, and passenger travel time were not included since small quantities of time saved can seldom be profitably utilized by those factors.

Cost per block hour information by aircraft type is compiled as part of the Form 41 data published by the CAB (Reference 13). That source lists flight crew costs but does not include cabin crew outlays. Information from informal CAB sources indicated domestic trunk cabin crew expense averaged $28-29 per attendant per block hour in 1976 dollars (Reference 14). Assumptions as to the number of cabin attendants per aircraft type permitted ready inclusion of that additional cost factor.

Average operating costs by aircraft class, presented in Table A-2 were calculated by developing airport-specific, weighted average cost estimates for each class based upon projected aircraft type totals (Reference 8). The average expense estimates of Table A-2 then were combined with the projected mixes for 1985 and 1995 to yield delay cost factors in dollars per minute of delay for each facility. Those factors permitted each airport's forecasted delay per operation values to be converted to delay costs. The estimated delay expenses were computed only for the two end years. Linear interpolation on delay costs or savings was used for the intermediate data points between 1985 and 1995. Summing across the airports' individual cost contributions provided the total for each separation set in each year.

Given the assumption that a VAS 3 nmi program would be fully operational prior to the 1985 base year, an alternate scenario to an AVS was defined. Data from the Transportation Systems Center indicated that the effectiveness of the present concept

TABLE A-1

ANNUAL PERCENT IFR* WEATHER
AT TOP U.S. AIR CARRIER AIRPORTS

AIRPORT	%IFR	AIRPORT	%IFR
ATL	14.5	LAX	25.7
BOS	16.2	LGA	16.5
CLE	15.1	MIA	2.4
DCA	11.5	MSP	11.5
DEN	6.5	ORD	16.3
DFW	8.4	PHL	15.7
DTW	14.1	PIT	17.1
EWR	16.8	SEA	16.3
IAH	17.1	SFO	15.5
JFK	15.5	STL	11.7

*IFR defined as ceiling ≤1500 feet and/or visibility below 3 nmi.

(from Reference 12).

TABLE A-2

AVERAGE 1976 OPERATING EXPENSE BY AIRCRAFT CLASS

FLYING AND MAINTENANCE COST ONLY

CLASS	WEIGHT DEFINING CLASS* (lbs)	AVG. OPERATING COST PER MINUTE (1976$)
Small (S)	< 12,500	$ 3.00 per minute
Large (L_1)	12,500 - 90,000	$ 7.75
Large (L_2)	90,000 - 300,000	$ 15.50
Heavy (H)	> 300,000	$ 31.75

*MAXIMUM CERTIFICATED GROSS TAKEOFF WEIGHT

VAS at the top 20 airports is expected to average 40 percent (Reference 5). It was assumed that the effectiveness during IFR conditions would also be 40%. The remaining 60 percent was assumed to be conducted under present day 3/4/5/4/6 spacings. This scenario (40% VAS standards and 60% today's standards) was adopted as a VAS baseline. The benefits of each proposed reduced standard across the 1985 and 1995 period were discounted back to 1985 using a ten percent annual rate and are presented from the standpoint of a range of AVS effectiveness percentages. The VAS baseline or fallback was assumed to pick up the remaining time. All delay benefits and costs are presented in 1976 dollars.

APPENDIX B

INPUT DATA FOR FULL DEMAND ANALYSES

Tables are presented which summarize several of the inputs used to develop delay savings estimates corresponding to the full demand, AVP projections (References 7,8) for the years 1985 and 1995 at the current top 20 air carrier airports. Mixes, presented in Table B-1, were generated based upon forecasted general aviation, air taxi, and air carrier operations. Those mix breakdowns in combination with representative arrival-departure runway configurations enabled capacity values to be calculated via the MITRE analytic model (Reference 9). The capacity estimates, shown in Tables B-2 and B-3, express operations per hour under the four sets of separation standards previously discussed in Figure 2-1. The final two tabulations, Table B-4 and B-5, summarize the average delay estimates for each airport as a function of the selected interaircraft spacing rules. By way of information, the VAS baseline used in the analyses was computed via a three step process. First, each airport's average delay per operation values were converted to total delay based on annual operations. The individual airport contributions then were summed and finally the sums for today's and the 3 nmi columns were weighted 60/40 respectively to yield a VAS baseline number. Bear in mind that the data given in this Appendix correspond to the full demands forecasted by AVP for the years 1985 and 1995.

TABLE B-1

FORECASTED 1985 AND 1995 MIX DISTRIBUTIONS
AIRPORTS ORDERED BY 1976 OPERATIONS

AIR CARRIER, AIR TAXI, AND GENERAL AVIATION

AIRPORT	1985 S	1985 L_1	1985 L_2	1985 H	1995 S	1995 L_1	1995 L_2	1995 H
ORD	7	2	54	37%	6	2	44	48%
ATL	15	15	37	33	17	10	27	46
LAX	6	9	25	60	5	10	15	70
DFW	11	18	61	10	12	22	50	16
JFK	0	3	27	70	0	3	25	72
LGA	5	11	72	12	5	10	70	15
SFO	13	20	33	34	12	15	34	39
DEN	13	20	39	28	12	15	38	35
MIA	7	15	30	48	7	10	35	48
BOS	19	24	45	12	19	25	41	15
DCA	28	15	50	7	29	15	44	12
PIT	22	25	47	6	25	29	37	9
STL	30	14	48	8	27	18	42	13
DTW	30	8	45	17	30	10	37	23
PHL	32	32	31	5	32	36	25	7
MSP	36	10	42	12	38	11	35	16
EWR	19	20	47	14	20	24	39	17
IAH	32	16	42	10	48	13	28	11
CLE	33	11	45	11	33	14	38	15
SEA	22	23	36	19	25	27	27	21

TABLE B-2

1985 IFR CAPACITIES IN OPERATIONS PER HOUR
20 AIRPORTS (30 CONFIGURATIONS), 4 SEPARATION SETS

AIRPORTS	RUNWAYS ARR	RUNWAYS DEP	SEPARATION SETS TODAY'S (3/4/5/4/6)	VAS (3 NMI)	AVS (2.5 NMI)	AVS (2.0 NMI)
ORD	*14L,14R	9L,27L	100	104	110	114
	**14L,14R	9L,27L	106	117	125	140
	32L,32R	32L,32R,27L	100	104	106	109
	27L,27R	32L,32R	111	123	137	156
ATL	8,9R	8,9L	102	107	119	131
LAX	24R,25L	24L,25R	101	108	132	153
DFW	17L,17R	13L,17R	110	115	122	138
	35L,35R	35L,35R	103	107	109	112
JFK	31R	31L	51	54	68	79
LGA	4	4	51	52	53	55
	22	13	57	59	66	71
SFO	28L	28R	52	55	65	78
DEN	35R	35L	55	57	63	68
	17R	8L/R	62	70	76	88
MIA	27L,27R	27R,27L	98	102	106	110
BOS	4R	9	55	57	64	69
	22L	22R	55	57	65	74
	33L	33L	51	53	55	56
DCA	36	36	52	54	55	56
PIT	28L	28R	56	60	66	79
STL	12R	12L	55	58	64	76
DTW	3L	3R	53	56	64	75
	27	21L	52	56	59	63
PHL	27R	27L	55	58	64	76

* - WET CONDITIONS

** - DRY CONDITIONS

TABLE B-2 (CONTINUED)

1985 IFR CAPACITIES IN OPERATIONS PER HOUR
20 AIRPORTS (30 CONFIGURATIONS), 4 SEPARATION SETS

AIRPORTS	RUNWAYS ARR	RUNWAYS DEP	SEPARATION SETS TODAY'S (3/4/5/4/6)	VAS (3 NMI)	AVS (2.5 NMI)	AVS (2.0 NMI)
MSP	29R	29L	53	57	64	72
EWR	4R	4L	54	57	65	74
IAH	8 8	14 8	55 51	59 54	65 55	78 57
CLE	23L	23R	54	57	64	72
SEA	16R	16L	53	56	64	73

TABLE B-3

1995 IFR CAPACITIES IN OPERATIONS PER HOUR
20 AIRPORTS (30 CONFIGURATIONS), 4 SEPARATION SETS

AIRPORTS	RUNWAYS ARR	RUNWAYS DEP	SEPARATION SETS TODAY'S (3/4/5/4/6)	VAS (3.0 NMI)	AVS (2.5 NMI)	AVS (2.0 NMI)
ORD	*14L,14R	9L,27L	99	103	110	114
	**14L,14R	9L,27L	105	117	125	140
	32L,32R	32L,32R,27L	100	104	106	109
	27L,27R	32L,32R	109	123	137	156
ATL	8,9R	8,9L	99	106	119	131
LAX	24R,25L	24L,25R	101	108	134	154
DFW	17L,17R	13L,17R	108	115	122	137
	35L,35R	35L,35R	102	106	109	112
JFK	31R	31L	55	55	70	83
LGA	4	4	51	52	53	55
	22	13	57	59	66	71
SFO	28L	28R	52	55	65	78
DEN	35R	35L	55	56	63	68
	17R	8L/R	61	70	76	88
MIA	27L,27R	27R,27L	98	102	106	110
BOS	4R	9	54	57	63	69
	22L	22R	54	57	65	74
	33L	33L	51	53	55	56
DCA	36	36	51	53	55	57
PIT	28L	28R	55	60	65	78
STL	12R	12L	54	57	64	76
DTW	3L	3R	51	55	63	74
	27	21L	51	55	59	63
PHL	27R	27L	54	57	64	76
MSP	29R	29L	52	56	63	71

* - WET CONDITIONS

** - DRY CONDITIONS

TABLE B-3 (CONTINUED)

1995 IFR CAPACITIES IN OPERATIONS PER HOUR
20 AIRPORTS (30 CONFIGURATIONS), 4 SEPARATIONS SETS

AIRPORTS	RUNWAYS ARR	RUNWAYS DEP	SEPARATION SETS TODAY'S (3/4/5/4/6)	VAS (3.0 NMI)	AVS (2.5 NMI)	AVS (2.0 NMI)
EWR	4R	4L	53	56	64	73
LAH	8	14	53	58	64	76
	8	8	51	54	55	57
CLE	23L	23R	53	56	63	72
SEA	16R	16L	52	56	63	72

TABLE B-4

1985 AVERAGE DELAY ESTIMATES (MINUTES/OPERATION)
FULL AVP-PROJECTED DEMANDS

AIRPORTS	SEPARATION STANDARDS GROUP			
	TODAY'S (3/4/5/4/6)	VAS (3 NMI)	AVS (2.5 NMI)	AVS (2.0 NMI)
ATL	3.06	1.94	0.65	0.23
BOS	25.48	20.98	13.69	8.25
CLE	2.02	1.36	0.63	0.29
DCA	12.26	9.69	8.87	7.13
DEN	14.27	11.16	8.26	4.79
DFW	0.11	0.08	0.06	0.04
DTW	2.13	1.18	0.48	0.21
EWR	0.50	0.37	0.20	0.12
IAH	3.73	2.00	1.25	0.71
JFK	14.83	12.79	5.84	2.81
LAX	0.64	0.36	0.10	0.05
LGA	14.37	12.16	6.95	4.97
MIA	0.07	0.05	0.04	0.03
MSP	3.89	2.37	1.10	0.47
ORD	13.48	8.85	6.47	4.55
PHL	28.28	22.97	14.11	3.23
PIT	24.38	18.59	10.00	1.52
SEA	0.44	0.31	0.18	0.10
SFO	23.42	18.32	5.64	0.70
STL	15.15	11.64	5.63	1.10

NOTE: THESE DELAY ESTIMATES ASSUME EACH SET OF SEPARATION STANDARDS TO BE OPERATIONAL 100% OF THE TIME.

TABLE B-5

1995 AVERAGE DELAY ESTIMATES (MINUTES/OPERATION)
FULL AVP-PROJECTED DEMANDS

AIRPORTS	SEPARATION STANDARDS GROUP TODAY'S (3/4/5/4/6)	VAS (3 NMI MIN.)	AVS (2.5 NMI MIN.)	AVS (2.0 NMI MIN.)
ATL	13.31	9.31	3.42	1.45
BOS	48.24	43.79	34.96	26.62
CLE	7.57	4.51	1.99	0.85
DCA	12.83	9.76	8.62	6.72
DEN	16.88	13.75	10.80	3.84
DFW	1.77	0.94	0.56	0.28
DTW	15.81	10.71	3.76	1.07
EWR	3.65	2.30	0.77	0.32
IAH	48.97	41.95	34.35	20.73
JFK	22.18	22.18	10.91	5.98
LAX	0.72	0.39	0.10	0.05
LGA	33.13	29.96	21.09	15.35
MIA	0.42	0.29	0.19	0.14
MSP	18.56	13.94	6.89	2.48
ORD	14.12	8.85	6.41	4.54
PHL	50.79	47.35	40.55	27.98
PIT	50.80	45.74	38.10	20.78
SEA	5.70	2.77	0.75	0.31
SFO	42.53	36.56	19.86	5.67
STL	28.37	23.97	15.68	6.17

NOTE: THESE DELAY ESTIMATES ASSUME EACH SET OF SEPARATION STANDARDS TO BE OPERATIONAL 100% OF THE TIME.

APPENDIX C

DATA FOR THE LOWER DEMAND ANALYSIS OF 2.5 NMI SEPARATIONS

This appendix supports the comparison of 2.5 nmi versus VAS or today's separation standards under lower-than-projected demand conditions. It presents mix, capacity, demand and delay data developed to aid in estimating delay savings at the top 20 airports. Demand levels were lowered by considering only air carrier and air taxi operations. The subsequent airport-dependent aircraft mixes are shown in Table C-1. Air taxi was assumed to be 25 percent small (S) and 75 percent large (L_1) aircraft.

Tables C-2 and C-3 present the hourly capacity for each of the 30 configurations as a function of runway grouping and separation standard. Following completion of delay estimates, multiple configuration facilities were reduced, using assumed or actual utilization data, to an airport average for each separation standard.

Not including the general aviation segment lowered the magnitude but did not change the shape of the forecasted 24 hour daily demand profile at each airport. Prior experience had demonstrated that delays considered acceptable for the purposes of this analysis could be generated if care was exercised to assume a reasonable hourly demand-to-capacity relationship. The subsequent demand adjustment process entailed comparing the capacity available over the busiest 16 hour period (0700 to 2300 hours) to the forecasted number of users in that same period. The general rule was established stating that for each hour in the 16 hour busy period, demand could exceed capacity by an amount equal to 1/16 of one hour's capacity computed using today's separation standards. In an equivalent sense, 16 hour demand could exceed 16 hour capacity by an amount equal to one hour's capacity.

Approximately half the airport demand profiles, now containing only air carrier and air taxi operations, satisfied the above test and required no additional corrections. In the remaining cases, operations were removed from hours in which demand exceeded capacity by more than 1/16 and were allocated to unsaturated periods within the 16 hour day. The redistribution was accomplished in a manner thought to closely duplicate probable airline shifts given excessive demand conditions. However, projected 16 hour demand sometimes exceeded available 16 hour capacity. The profile, in those situations, was adjusted to one level, 16 hour peak equal in magnitude to 1.06525 x capacity. Excess operations remaining were discarded

TABLE C-1

PREDICTED 1985 AND 1995 MIX DISTRIBUTIONS
AIR CARRIER AND AIR TAXI ONLY

Airport	1985 S	1985 L_1	1985 L_2	1985 H	1995 S	1995 L_1	1995 L_2	1995 H
ORD	3	11	62	24%	4	11	51	34%
ATL	1	3	76	20	1	4	67	28
LAX	6	17	47	30	7	23	33	37
DFW	6	19	64	11	8	23	52	17
JFK	3	10	48	39	4	13	34	49
LGA	3	9	76	12	4	12	66	18
SFO	4	14	55	27	6	18	41	35
DEN	7	20	61	12	8	25	50	17
MIA	3	10	58	29	4	13	49	34
BOS	7	28	51	14	9	28	46	17
DCA	7	19	65	9	7	20	57	16
PIT	9	29	55	7	12	34	44	10
STL	6	19	64	11	8	23	52	17
DTW	4	11	62	23	4	14	51	31
PHL	14	40	39	7	15	46	30	9
MSP	5	14	62	19	6	18	53	23
EWR	7	23	54	16	9	28	44	19
IAH	7	22	58	13	8	24	49	19
CLE	5	16	64	15	6	20	53	21
SEA	9	27	42	22	11	32	32	25

TABLE C-2

1985 IFR CAPACITIES (OPERATIONS PER HOUR) BY CONFIGURATION
AIR CARRIER AND AIR TAXI ONLY
20 AIRPORTS, 3 SEPARATION GROUPS

AIRPORTS	RUNWAYS ARR	RUNWAYS DEP	SEPARATION GROUPS TODAY'S (3/4/5/4/6)	VAS (3 NMI)	AVS (2.5 NMI)
ORD	*14L,14R	9L,27L	102	105	110
	**14L,14R	9L,27L	109	117	125
	32L,32R	32L,32R,27L	102	105	106
	27L,27R	32L,32R	115	123	137
ATL	8,9R	8,9L	107	110	121
LAX	24R,25L	24L,25R	106	111	132
DFW	17L,17R	13L,17R	111	116	123
	35L,35R	35L,35R	104	106	109
JFK	31R	31L	52	55	66
LGA	4	4	51	52	53
	22	13	58	59	66
SFO	28L	28R	55	57	67
DEN	35R	35L	60	60	64
	17R	8L/R	67	71	78
MIA	27L,27R	27R,27L	100	103	106
BOS	4R	9	56	58	65
	22L	22R	56	58	66
	33L	33L	52	53	54
DCA	36	33	58	59	63
PIT	28L	28R	58	61	68
STL	12R	12L	57	59	68
DTW	3L	3R	55	57	67
	27	21L	54	57	62
PHL	27R	27L	56	59	66

* - WET CONDITIONS

** - DRY CONDITIONS

TABLE C-2 (CONTINUED)

1985 IFR CAPACITIES (OPERATIONS PER HOUR) BY CONFIGURATION
AIR CARRIER AND AIR TAXI ONLY
20 AIRPORTS, 3 SEPARATION GROUPS

AIRPORTS	RUNWAYS ARR	RUNWAYS DEP	SEPARATION GROUPS TODAY'S (3/4/5/4/6)	SEPARATION GROUPS VAS (3 NMI)	SEPARATION GROUPS AVS (2.5 NMI)
MSP	29R	29L	55	57	67
EWR	4R	4L	55	58	66
IAH	8 8	14 8	58 52	62 53	69 54
CLE	23L	23R	56	58	67
SEA	16R	16L	54	56	66

TABLE C-3

1995 IFR CAPACITIES (OPERATIONS PER HOUR) BY CONFIGURATION
AIR CARRIER AND AIR TAXI ONLY
20 AIRPORTS, 3 SEPARATION GROUPS

AIRPORT	RUNWAYS ARRIVAL	RUNWAYS DEPARTURE	SEPARATION GROUPS TODAY'S (3/4/5/4/6)	VAS (3 NMI)	AVS (2.5 NMI)
ORD	*14L,14R	9L,27L	100	104	110
	**14L,14R	9L,27L	107	116	124
	32L,32R	32L,32R,27L	101	104	106
	27L,27R	32L, 32R	112	123	137
ATL	8,9R	8,9L	105	108	120
LAX	24R,25L	24L,25R	103	110	130
DFW	17L,17R	13L,17R	109	115	123
	35L,35R	35L,35R	102	106	109
JFK	31R	31L	51	54	66
LGA	4	4	50	52	53
	22	13	56	58	66
SFO	28L	28R	53	55	66
DEN	35R	35L	58	59	64
	17R	8L/R	65	70	77
MIA	27L,27R	27R,27L	99	102	106
BOS	4R	9	55	57	64
	22L	22R	55	57	66
	33L	33L	51	53	54
DCA	36	33	56	58	63
PIT	28L	28R	57	61	67
STL	12R	12L	55	57	66
DTW	3L	3R	53	56	66
	27	21L	53	55	62
PHL	27R	27L	55	58	65

* - WET CONDITIONS

** - DRY CONDITIONS

TABLE C-3 (CONTINUED)

1995 IFR CAPACITIES (OPERATIONS PER HOUR) BY CONFIGURATION
AIR CARRIER AND AIR TAXI ONLY
20 AIRPORTS, 3 SEPARATION GROUPS

AIRPORT	RUNWAYS ARRIVAL	RUNWAYS DEPARTURE	SEPARATION GROUPS TODAY'S (3/4/5/4/5)	SEPARATION GROUPS VAS (3 NMI)	SEPARATION GROUPS AVS (2.5 NMI)
MSP	29R	29L	54	57	66
EWR	4R	4L	54	57	66
IAH	8 8	14 8	57 51	62 53	68 54
CLE	23L	23R	55	57	66
SEA	16R	16L	53	56	65

implying diversions to other facilities. The demand for the remaining 8 hours of the 24 hour day was not modified. Tables C-4 and C-5 summarize the daily demand at each airport with general aviation included, with general aviation removed, and the actual amount accommodated given available capacity.

It must be emphasized that demand limitations were imposed in accordance with capacity levels computed under today's separation rules. Closer interaircraft spacings such as provided by a 2.5 nmi AVS would permit an additional increment of demand to be serviced which is not accounted for in this analysis. In theory, society could convert the time savings produced by closer longitudinal spacings into additional accommodated demand. Not including the demand increment that could be handled at the closer separations helps to assure a conservative analysis of the cost-effectiveness of AVS.

The final set of tables (C-6 and C-7) in this Appendix summarize the estimated average delay per operation quantities for each airport. The delay numbers were calculated by the MIT 'DELAYS' model (Reference 11) using as input the capacities and demand profiles modified as discussed above.

TABLE C-4

SUMMARY OF GENERAL AVIATION AND CAPACITY ADJUSTMENTS MADE TO PROJECTED 1985 DAILY OPERATIONS

AIRPORT	1985 DAILY OPS WITH G/A	1985 DAILY OPS WITHOUT G/A	OPS ADJUSTED TO CAPACITY*	OPS REJECTED BY CAPACITY
ATL	1704	1540	1540	0
BOS	1170	1008	1001	7
CLE	803	529	529	0
DCA	992	753	753	0
DEN	1351	1066	1066	0
DFW	1389	1323	1323	0
DTW	860	627	627	0
EWR	715	622	622	0
IAH	910	655	655	0
JFK	1143	1069	1040	29
LAX	1490	1315	1315	0
LGA	1030	1000	970	30
MIA	1071	871	871	0
MSP	896	559	559	0
ORD	2027	1945	1918	27
PHL	1293	1019	1019	0
PIT	1208	1008	1008	0
SEA	712	595	595	0
SFO	1170	1022	1007	15
STL	1110	797	797	0

* - DURING 16 HOUR DAY (0700-2300), DEMAND ALLOWED TO EXCEED HOURLY CAPACITY BY 1/16 OF THE HOURLY CAPACITY.

TABLE C-5

SUMMARY OF GENERAL AVIATION AND CAPACITY
ADJUSTMENTS MADE TO PROJECTED 1995 DAILY OPERATIONS

AIRPORT	1995 DAILY OPS WITH G/A	1995 DAILY OPS WITHOUT G/A	OPS ADJUSTED TO CAPACITY*	OPS REJECTED BY CAPACITY
ATL	2027	1863	1863	0
BOS	1488	1329	1023	306
CLE	956	663	663	0
DCA	986	751	751	0
DEN	1474	1389	1152	237
DFW	1792	1712	1712	0
DTW	1090	795	795	0
EWR	932	819	819	0
IAH	1526	852	852	0
JFK	1408	1334	1065	269
LAX	1510	1436	1436	0
LGA	1241	1156	984	172
MIA	1312	1082	1082	0
MSP	1148	715	715	0
ORD	2027	1945	1874	71
PHL	1800	1441	1065	376
PIT	1619	1362	1055	307
SEA	962	789	789	0
SFO	1411	1301	1036	265
STL	1318	1038	1022	16

* - DURING 16 HOUR DAY (0700-2300), DEMAND ALLOWED TO EXCEED HOURLY CAPACITY BY 1/16 OF THE HOURLY CAPACITY.

TABLE C-6

1985 PROJECTED AVERAGE DELAY ESTIMATES (MINUTES/OPERATION)
AIR CARRIER AND AIR TAXI ONLY

AIRPORTS	SEPARATION STANDARDS GROUP		
	TODAY'S (3/4/5/4/6)	VAS (3.0 NMI)	AVS (2.5 NMI)
ATL	0.75	0.57	0.21
BOS	5.73	3.87	1.93
CLE	0.18	0.15	0.09
DCA	0.44	0.36	0.24
DEN	1.98	1.31	0.64
DFW	0.07	0.06	0.04
DTW	0.23	0.20	0.11
EWR	0.24	0.20	0.12
IAH	0.27	0.21	0.16
JFK	4.36	2.24	0.36
LAX	0.21	0.15	0.07
LGA	5.39	4.19	2.62
MIA	0.02	0.01	0.01
MSP	0.18	0.15	0.08
ORD	3.34	1.99	1.48
PHL	4.94	3.00	0.69
PIT	4.01	2.17	0.60
SEA	0.20	0.17	0.10
SFO	3.82	2.37	0.41
STL	0.71	0.56	0.22

NOTE: THESE DELAY ESTIMATES ASSUME EACH SET OF SEPARATION STANDARDS TO BE OPERATIONAL 100% OF THE TIME.

TABLE C-7

1995 PROJECTED AVERAGE DELAY ESTIMATES (MINUTES/OPERATION)
AIR CARRIER AND AIR TAXI ONLY

AIRPORTS	SEPARATION STANDARDS GROUP		
	TODAY'S (3/4/5/4/6)	VAS (3.0 NMI)	AVS (2.5 NMI)
ATL	2.64	1.58	0.32
BOS	5.95	3.74	1.72
CLE	0.57	0.44	0.19
DCA	0.56	0.41	0.24
DEN	2.37	1.42	0.65
DFW	0.81	0.41	0.25
DTW	0.99	0.69	0.25
EWR	1.19	0.83	0.32
IAH	1.79	1.06	0.68
JFK	5.65	2.65	0.37
LAX	0.40	0.25	0.10
LGA	6.80	4.83	2.64
MIA	0.07	0.05	0.04
MSP	0.77	0.58	0.21
ORD	4.26	2.22	1.57
PHL	4.82	2.74	0.62
PIT	6.59	3.09	0.79
SEA	0.78	0.53	0.23
SFO	5.80	3.27	0.45
STL	4.80	3.01	0.49

NOTE: THESE DELAY ESTIMATES ASSUME EACH SET OF SEPARATION STANDARDS TO BE OPERATIONAL 100% OF THE TIME.

APPENDIX D

DEMAND ADJUSTMENTS AND CAPACITIES USED TO COMPARE 2.0 AND 2.5 NMI SEPARATION STANDARDS

The demand sensitivity analysis conducted to probe within the reduced separations concept and compare the benefits of 2.0 relative to 2.5 nmi minimum separation standards was based upon 1985 and 1995 demand profiles adjusted to the available airport capacities. Heuristic rules guided the development of the hourly demand profiles in order to consider the impact of a less peaked demand pattern on the 2.0 nmi delay savings.

The demand adjustment procedure was similar in concept to that developed for the previous VAS versus 2.5 nmi demand sensitivity study (Appendix C). Each airport's projected demand pattern across the busiest 16 hours (0700-2300 hours) of the 24 hour operating day was compared to the available capacity in that period. The capacity utilized was that computed under 2.5 nmi arrival standards. In accordance with a general rule of thumb, hourly demand was permitted to exceed hourly capacity by only 1/16 of the capacity. The net effect allowed 16 hour demand to overstep 16 hour capacity by an amount equal to one hour's capacity. Most profiles required little or no peak flattening. However, in some cases, a substantial number of operations could not be accommodated within the level, 16 hour capacity constraint envelope. Those operations were discarded and not considered further in this analysis. Demands in the remaining 8 hours were not adjusted. Table D-1 summarizes the changes made to the 1985 demand profiles for the top 20 airports. It is apparent that the capacities computed under 2.5 nmi separations are adequate to handle virtually all of the projected daily demands, including general aviation. The situation under 1995 conditions, however, required removing a larger portion of the daily demand at many airports as Table D-2 illustrates.

Capacity constraints at six of the facilities (BOS, DEN, LGA, PHL, PIT, and SFO) necessitated rejecting a demand component greater than the total 24 hour general aviation community. It was assumed, for the purposes of analysis, that the greater flexibility of that user class would permit them to divert to other facilities in order to escape the high delay periods at their first choice airports. Capacities for those six airports were adjusted slightly upwards in accordance with a revised mix consisting of only air carrier and air taxi airport users. A second round of demand modification then was performed on those six airports resulting in the accommodation of a few additional

TABLE D-1

2.0 VERSUS 2.5 NMI STUDY
SUMMARY OF ADJUSTMENTS TO PROJECTED 1985 DAILY DEMAND

	16 HOUR* TOTAL DEMAND	HOURLY CAPACITY UNDER 2.5 NMI	AVAILABLE 16+1 HOURS CAPACITY	OPERATIONS REJECTED	24 HOUR GENERAL AVIATION COMPONENT
ATL	1467	119	2023	0	164
BOS	1092	62	1056	36	162
CLE	721	64	1088	0	274
DCA	983	55	935	48	239
DEN	1299	73	1237	62	285
DFW	1236	119	2019	0	66
DTW	786	63	1068	0	233
EWR	638	65	1105	0	93
IAH	828	62	1063	0	255
JFK	988	68	1156	0	74
LAX	1324	132	2244	0	175
LGA	1014	63	1067	0	30
MIA	957	106	1802	0	200
MSP	850	64	1088	0	337
ORD	1872	121	2057	0	82
PHL	1197	64	1088	109	274
PIT	1154	66	1122	32	200
SEA	632	64	1088	0	117
SFO	1065	65	1105	0	148
STL	1056	64	1088	0	313

* 16 HOURS = 0700 to 2300, DEMAND FROM REFERENCES 7, 8, 10.

TABLE D-2

2.0 VERSUS 2.5 NMI STUDY
SUMMARY OF ADJUSTMENTS TO PROJECTED 1995 DAILY DEMAND

	16 HOUR* TOTAL DEMAND	HOURLY CAPACITY UNDER 2.5 NMI	AVAILABLE 16+1 HOURS CAPACITY	OPERATIONS REJECTED	24 HOUR GENERAL AVIATION COMPONENT
ATL	1745	119	2023	0	164
BOS	1389	62	1050	339*	159
CLE	859	63	1071	0	293
DCA	978	55	935	43	235
DEN	1418	73	1237	181*	85
DFW	1594	119	2019	0	80
DTW	996	62	1061	0	295
EWR	831	64	1088	0	113
IAH	1390	62	1055	340	674
JFK	1217	70	1190	27	74
LAX	1341	134	2278	0	74
LGA	1222	63	1067	155**	85
MIA	1172	106	1802	0	230
MSP	1089	63	1071	18	433
ORD	1872	121	2058	0	82
PHL	1666	64	1088	578**	359
PIT	1546	65	1105	441**	257
SEA	853	63	1071	0	173
SFO	1284	65	1105	179**	110
STL	1253	64	1088	165	280

* 16 HOURS = 0700 TO 2300. DEMAND FROM REFERENCES 7, 8, 10

** ALL GA DEMAND REMOVED, CAPACITY ADJUSTED ACCORDINGLY operations at each facility. Table D-2 presents the new result of the demand-capacity reconciliation for 1995. The projected 1985 and 1995 hourly capacities for the 2.5 nmi rules (upon which the demand adjustments were based) as well as the 2.0 nmi separation capacities are summarized in Table D-3. All of the values are structured upon a three component demand consisting of air carrier, air taxi, and general aviation with the exception of six airports in 1995. Demands rejected due to the available capacity envelope were not further considered in this analysis.

The subsequent average delay per operation estimates for 2.5 nmi and 2.0 nmi separation capacities standards are given in Table D-4. Again these values are derived from demand profiles adjusted in accordance with hourly capacity limitations.

TABLE D-3

CAPACITIES USED FOR 2.0 VERSUS 2.5 NMI DEMAND SENSITIVITY STUDY
DEMAND = AIR CARRIER + AIR TAXI + GENERAL AVIATION EXCEPT AS NOTED
(OPERATIONS PER HOUR)

AIRPORT	RUNWAYS ARR	RUNWAYS DEP	1985 2.5 NMI	1985 2.0 NMI	1995 2.5 NMI	1995 2.0 NMI
ORD	(WET)14L,14R	9L,27L	110	114	110	114
	(DRY)14L,14R	9L,27L	125	140	125	140
	32L,32R	32L,32R,27L	106	109	106	109
	27L,27R	32L,32R	137	156	137	156
ATL	8,9R	8,9L	119	131	119	131
LAX	24R,25L	24L,25R	132	153	134	154
DFW	17L,17R	13L,17R	122	138	122	137
	35L,35R	35L,35R	109	112	109	112
JFK	31R	31L	68	79	70	83
LGA	4	4	53	55	53*	55*
	22	13	66	71	66*	71*
SFO	28L	28R	65	78	66*	80*
DEN	35R	35L	63	68	64*	68*
	17R	8L/R	76	88	77*	90*
MIA	27L,27R	27R,27L	106	110	106	110
BOS	4R	9	64	69	64*	70*
	22L	22R	65	74	66*	75*
	33L	33L	55	56	54*	56*
DCA	36	36	55	56	55	57
PIT	28L	28R	66	79	67*	81*
STL	12R	12L	64	76	64	76
DTW	3L	3R	64	75	63	74
	27	21L	59	63	59	63
PHL	27R	27L	64	76	65*	78*
MSP	29R	29L	64	72	63	71

*-AIRPORTS FOR WHICH CAPACITY BASED ON AIR CARRIER + AIR TAXI DUE TO EXCESSIVE DEMAND.

TABLE D-3 (CONTINUED)

CAPACITIES USED FOR 2.0 VERSUS 2.5 NMI DEMAND SENSITIVITY STUDY
DEMAND = AIR CARRIER + AIR TAXI + GENERAL AVIATION EXCEPT AS NOTED
(OPERATIONS PER HOUR)

AIRPORT	RUNWAYS ARR	RUNWAYS DEP	1985 2.5 NMI	1985 2.0 NMI	1995 2.5 NMI	1995 2.0 NMI
EWR	4R	4L	65	74	64	73
IAH	8 8	14 8	65 55	78 57	64 55	76 57
CLE	23L	23R	64	72	63	72
SEA	16R	16L	64	73	63	72

TABLE D-4

AVERAGE DELAY PER OPERATION ESTIMATES
2.0 VERSUS 2.5 NMI STUDY
(MINUTES PER OPERATION)

AIRPORT	1985 2.5 NMI	1985 2.0 NMI	1995 2.5 NMI	1995 2.0 NMI
ATL	0.61	0.21	2.62	0.55
BOS	7.12	4.22	6.69	4.17
CLE	0.61	0.26	1.38	0.48
DCA	4.37	3.02	4.46	2.96
DEN	2.65	1.24	2.54	1.29
DFW	0.06	0.04	0.55	0.28
DTW	0.48	0.21	3.08	0.74
EWR	0.19	0.12	0.73	0.30
IAH	1.23	0.70	7.97	3.86
JFK	2.24	0.45	4.88	0.49
LAX	0.11	0.06	0.11	0.06
LGA	6.89	4.82	8.06	5.39
MIA	0.03	0.02	0.12	0.08
MSP	0.87	0.32	4.28	0.78
ORD	5.99	4.31	5.94	4.30
PHL	5.39	0.61	5.01	0.55
PIT	5.89	0.55	5.71	0.52
SEA	0.17	0.11	0.72	0.29
SFO	4.03	0.45	5.19	0.48
STL	3.73	0.47	4.16	0.49

APPENDIX E

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